Weather Forecasting Accuracy

Ross Island, Antarctica

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Abstract

The forecast accuracy of AMPS (Antarctic Mesoscale Prediction System) for the Ross Island region was analysed during 20th to 31st December 2009. Forecast outputs are correlated with AWS (automatic weather stations) observations at five sites around Ross Island. Results are presented in the appendix. Appendix 1 presents the PCAS (Post Graduate Certificate in Antarctica Studies) AWS observations and corresponding forecasts, appendix 2 Windless Bight AWS, appendix 3 Willie Field AWS, appendix 4 Emilia AWS and appendix 5 is a case study of Christmas day. Air pressure was forecasted the most accurately for all forecast hours, resulting in a <3hpa variance and AMPS bias not greater than -2.45hpa. The timing of a change in temperature was accurately forecasted within 2 hours but the extent of the change was less accurate. Relative humidly was lower than forecasted over Christmas day with a +16% AMPS bias. This paper discusses the most notable results found in the appendix in an aim to determine forecast accuracy.

Introduction

As part of the Post Graduate Certificate in Antarctica Studies (PCAS) a field trip to Antarctica was undertaken between 20th to 31st December 2009. During this time weather observations were taken every 10 minutes from the automatic weather station (AWS) that PCAS constructed. Many of the forecasts that were issued for our field camp site in Windless Bight were inaccurate. The forecast inaccuracy could be human error in interpreting the forecast models, or the forecast models could be inaccurate. The forecast model with the greatest resolution of Ross Island region is the Antarctic Mesoscale Prediction System (AMPS)(AMPS, 2010). This study aims to find the accuracy of AMPS forecasts during 20th to 31st December 2009 in the Ross Island region.

Atmospheric dynamics of the region are complex which is in part due to the terrain; 3500-m-high Trans Antarctic Mountains are located to the west of the station, and Scott Base itself is located on Ross Island at the base of a 3794-m active volcano, Mt. Erebus. The area is also subjected to the influence of three dissimilar air masses: cold dry air from the high continental plateau to the west; moister but still cool air from the low-lying Ross Ice Shelf to the south; and relatively warm moist air from the Ross Sea to the north. This mixture of air masses provide the ingredients for very changeable weather that could cause many issues for conventional forecast models. There have been many documentations of these air masses including: cyclonically forced winds propagating northward along the Transantarctic Mountains e.g., (O'Connor et al. 1994), intense katabatic winds flowing from the nearby glacial valleys e.g., (Bromwich, 1991); and the most active regions of mesoscale cyclogenesis on Earth adjacent to Ross Island (Bromwich 1991). The ability to forecast these conditions are crucial for aircraft operations, as local aircraft operations are commonly suspended due to blowing snow and fog.

A forecast accuracy analysis was also undertaken by Bromwich et al, 2005, from September 2001 through to August 2003. They concluded that the high resolution AMPS forecast were more sensitive to spatial and temporal changes than the lower resolution models, which represents an overall improvement in forecast skill. The correlation coefficients for this high resolution model were found to be low. The methods that were used by Bromwich et al, 2005 are replicated in this study, but are analyzed in more detail and over a shorter time period.

Automatic Weather Stations

All the AWS used in this study are within the forecast range of the 1.7km resolution Ross Island AMPS. The locations of the stations are circled below

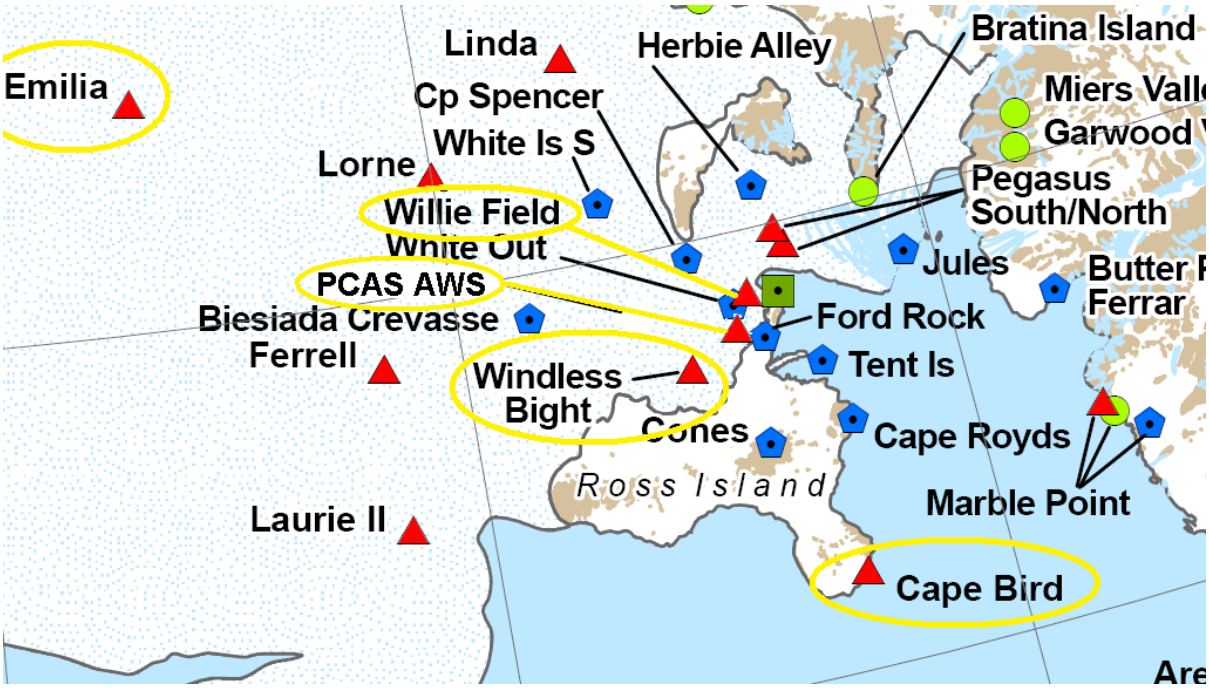


Figure1, The AWS circled in yellow are the AWS used in this study and the corresponding red triangle is the approximate location of the stations (AAWSP, 2010).

The location of the PCAS camp is: S 77° 47' 30.6", E 166° 58' 23.8, located several kilometres southwest of Scott Base on the Ross Ice Shelf. An AWS taking measurements every 10 minutes was set up in this location for the duration of camp, 24th to 31st of December 2009.

The other AWS used are permanent which were set up by University of Wisconsin. The data obtained by these AWS have been archived and are freely accessible to the public (AAWSP, 2010).

Willie Field is 14 meters above sea level and is located S 77° 86' 60", E 166° 58' 98.3 (AAWSP, 2010), which is very close to the PCAS AWS. The close proximity of the two AWS should provide similar observations. Any variance in the observations could give insight into the spatial scale of local weather patterns. If there is any observational variances will the AMPS model forecast it?

Windless Bight AWS is located in the centre of the stagnation zone, usually there is little or no wind at the station. It is located S 77° 72' 30", E 167° 69' 20 and is 40 meters above sea level (AAWSP, 2010). This AWS was chosen because it is directly south of Mt Erebus, where the dominant southerly wind is deflected to the eastern and western side of the mountain. The local weather patterns in the area are greatly influenced by the topography of the mountain. AMPS accuracy in this area should reflect how well the forecast model takes topography into account.

Emilia AWS is located on the Ross Ice Shelf where it is exposed to the strong katabatic winds. This station was chosen because it will be useful in assessing how accurate the AMPS forecasting is at forecasting katabatic winds. It will also be useful in determining the effect of topography on forecast accuracy, as this site has far less relief than the other AWS. It is located 52.3 meters above sea level, located at S 78° 48' 80", E 173° 13' 40 (AAWSP, 2010).

Cape Bird AWS is located S 77° 21' 70", E 166° 43' 90 at a height of 38 meters (AAWSP, 2010). Located on the northern side of Ross Islands it is exposed to a more maritime climate. The sea ice breaks away during summer and the snow melts away exposing the black volcanic rocks. This site was chosen to see if AMPS accuracy during Christmas day differed from the sites of the ice shelf.

Methods

AWS observation data was obtained for Willie Field AWS, Windless Bight AWS, Cape Bird AWS and Emilia AWS from the University of Wisconsin Archives (AAWSP, 2010). Observational data is recorded every 10 minutes for all AWS. All the daily observations taken at 0:00am and 12:00pm during 20th to 31st December were selected. Hourly observations from 00:00am on the 25th December 2009 were taken for analysing Christmas day in more detail. The same observational data was extracted from the PCAS AWS.

The corresponding AMPS forecast data was extracted and entered into excel (AMPS, 2010). Temperatures were converted to degrees celsius. Air pressure was converted to hectopascals. The U and V component of the wind was converted to wind velocity (m/s) and direction (°) using equations shown in appendix 6.

The forecasts for 0, 24 and 36 hours were all graphed separately with their corresponding observations. The forecasts used are for 2 meter air temperature, air pressure at AWS

altitude, relative humidity, wind velocity and wind direction. These were chosen because the AWS had good quality data.

AMPS bias was calculated by calculating the average difference between a forecast and observation; this has been added to each graph. The trend of this average difference was used to calculate the r value (correlation coefficient), which is a measure of how well the forecast and observation are correlated (1=100% correct).

All the results are located in the appendix and will be referred to in text by a number, letter and then a roman numeral. The number refers to appendix number, letter refers to forecast hour and the roman numeral is the observation type (only appendix 1 to 4). For example **2C**iii is in appendix 2 under 36 hour forecast for wind velocity.

Christmas day was chosen as a case study due to the rapid changes throughout the day. The forecast issued at 0:00am 25th December is analysed for every hour. The results are found in appendix 5.

Hypothesis

- AMPS forecast accuracy will decrease with increased forecast hour.
- AMPS bias will increase with forecast hour

Evaluation of AMPS

Willie Field AWS & PCAS AWS

The observation data for air pressure from the Willie Field AWS is incorrect (**3A**i (appendix reference)). A positive AMPS bias of +17.7hpa is far higher than the PCAS AWS, where only a +0.08hpa bias occurs (**1A**ii), thus highly likely an observation error.

Temperature observations were very similar between these two stations (Appendix **1A**i & **3A**ii) as expected from their close proximity to each other. Amps 0 hour forecast of these temperatures had an average negative bias of -4.7^{o}C. This large negative bias is not present in the 24 and 36 hour forecasts for both AWS (Appendix **1B**i, **1C**i, **3B**ii and **3C**ii). Reasons for this large bias in the 0 hour forecast are unknown. Although the 0 hour forecast does have a greater correlation than the 24 and 36 hour forecast, as expected.

Wind velocity 0 hour forecasts are mostly within ±2m/s for both sites, except for Christmas day, where AMPS forecasted 0.8m/s and AWS recorded 3.4m/s for PCAS and 6.9m/s for Willie Field (**1A**iii and **3A**iii). Long range forecasts (24 and 36 hour) are mostly within ±3m/s (**1B**iii, **1C**iii, **3B**iii and **3C**iii).

Wind direction forecasts are very similar between the two AWS sites, but the observations have a greater variability (**1A**iv and **3A**iv). For example between the 28th to 30th December AMPS forecasted a NNW (~345°) wind, PCAS camp observed this direction (approximately), while Willie AWS observed ~SE winds. The proximity of the two stations and the large difference in observed wind directions show the small scale of local weather patterns. The resolution of AMPS models would need to become greater to pick up these differences in wind flow. The 24 and 36 hour forecasts decrease in accuracy for PCAS AWS (as expected), but increase for Willie Field AWS (**1B**iv, **1C**iv, **3B**iv and **3C**iv). Possible reasons for inaccuracy of forecasted wind directions for Willie Field include: Small scale local winds not picked up in model, surrounding terrain effecting forecast results, calculation error (human error) or AWS instrument error.

Windless Bight AWS

During the 11 days of AMPS forecasts for the Windless Bight area wind velocity was over estimated and forecasts failed to predict a relatively high wind event on the 21st December (Appendix **2A**iii, **2B**iii and **2C**iii). The AMPS bias ranged from +0.53m/s for 24 to 36 hour forecasts to 0.98m/s for the 0 hour forecasts. Over the 21st December winds were averaging at 5m/s and were only forecasted to reach 1-2m/s. Over the whole period there is a low correlation in accuracy of forecasting wind velocity.

The 0 hour forecast for air temperature, as found in the Willie and PCAS AWS, had a strong positive bias of 4.43°C (**2A**ii). This bias is not present in the 24 and 36 hour forecasts with a accuracy of forecasted temperatures within ±3°C (**2B**ii and **2C**ii). Air pressure is correlated relatively accurately; all forecasts are within ±4hpa of the AWS observation (**2A**i, **2B**i and **2C**i). The 0 hour forecasts predicted wind direction well, except for westerly winds where the forecast was off by almost 180° (**2A**iv). The forecast accuracy progressively decreased with increased forecast time, from the 24 hour to 36 hour forecasts (**2B**iv and **2C**iv).

Emilia AWS

Emilia AWS is exposed out on the Ross Ice Shelf where it is commonly exposed to katabatic winds (*Figure1*). No strong katabatic winds were observed during 20th to 31st December 2009, but a 6m/s northerly occurred on the 27th (**4A**iii). This northerly coincided with warm air and a drop in pressure as the low moved into the area (**4A**i and **4A**ii). AMPS forecasted the pressure drop accurately, just an -3hpa bias which is most likely a height calibration error (**4A**i, **4B**i and **4C**i). The forecasts for 0 hours forecasted the increase in temperature and wind velocity, but underestimated the intensity (**4A**ii and **4A**iii). The long range forecasts failed to forecast this warm northerly (**4B**ii, **4B**iii, **4C**ii and **4C**iii).

Case Study: Christmas Day 2009

From all the days analysed the forecast for Christmas day appears to be the most inaccurate. The AMPS forecast issued 0:00am 25th December 2009 is analysed for every forecasted hour until the 36th hour. All the observations that were analysed are the same as above, except for the addition of relative humidity which is also graphed (appendix 5). Cape Bird AWS is also incorporated into the results.

During the morning of Christmas day temperatures were lower than forecasted by up to 3°C (**5B**i). Around 12pm temperatures dipped down to -12°C and then sharply rose to 0°C by midnight (0:00am 26th) bringing snow and fog (**5C**i and **5D**i). The timing of this increase in temperature was forecasted within an hour. The rate and intensity of this warm air was under forecasted, as a ~-3°C bias of AMPS occurs between 24 to 30 hours (**5B**i and **5C**i). Temperatures at the Emilia AWS were also cooler than forecasted for the first 5 hours and warmer 24 to 36 hours. Temperatures at Cape Bird were more stable ranging from -8°C to -11°C, but were forecasted to range from -3°C to -6°C (**5A**i). This huge AMPS bias of +5.13°C could indicate the warm air was delayed; this is unlikely as it was correctly forecasted at the other AWS sites. The resolution of the model and topography is unlikely to be the cause because temperatures were cooler than forecasted. Instrument or human error is more likely.

Air pressure did not go as low as forecasted in the Windless Bight (**5D**ii), but the timing of pressure changed was forecasted accurately. Most of the stations had large biases, most likely to calibration errors, but also show the accuracy of timing of pressure changes (**5A**ii, **5B**ii and **5C**ii).

Wind velocity 3-7 hour forecasts were over estimated for all stations (**5B**iii, **5C**iii and **5D**iii). Forecasted hours 11-24 had a strong correlation for Windless Bight, while Emilia and Cape Bird AWS had poor correlations (**5A**iii). Wind velocities during the hours 25-34 were all underestimated, except for Emilia, where they were over estimated.

Relative humidity for Emilia, Windless Bight and Willie had a positive AMPS bias 14% to 21% (**5B**v, **5C**v and **5D**v). This anomaly is not present over at the Cape Bird AWS, where there is a more maritime influence (**5A**v). This is a significant inaccuracy of the AMPS models for this day.

Overall Results

Forecasts for 0 hours of the overall AMPS bias.

AMPS Bias	Temperature (°C)	Pressure	Wind Velocity	Wind Direction
0 hour forecasts	-3.8	0.47hpa	0.34m/s	67°
24 hour forecasts	0.11	-1.3hpa	-0.02m/s	14.8°
36 hour forecasts	0.3	-2.45hpa	-0.78m/s	-8.07°

The average AMPS bias of air temperature for 0 hour forecast is -3.8°C, the cause of this large bias is unknown. The 24 and 36 hour forecasts both have a small positive AMPS bias. Air Pressure has a small bias that increases with forecast hour. Wind velocity also has a low bias. A large 67° AMPS bias occurs for wind direction in the 0 hour forecast, this large bias is not present in the 24 and 36 hour forecasts, as with air temperature. The initial hypothesis of increased AMPS biases with increased forecast hour is mostly correct for 24 and 36 hour forecasts, but 0 hour forecasts have the higher bias. The cause of this is most likely a data processing error.

AMPS Accuracy

AMPS Accuracy	Temperature (°C)	Pressure (hpa)	Wind Velocity (m/s)
0 hour forecasts	±11.25	±1	±4.2
24 hour forecasts	±7.75	±2.2	±3.5
36 hour forecasts	±5.7	±3.5	±3

This table shows the average maximum variance of forecast and actual observation. The greater the variance is, the less accurate the forecast. The initial hypothesis was for forecast accuracies to decrease with forecast hour. This hypothesis is true for air pressure, where variance on average increases with forecast hour. Temperature and wind velocity on average decrease with forecast hour, which disproves the hypothesis. The 0 hour forecasts have the greater bias, which has helped to increase variance. With the correct calibration of 0 hour forecasts the accuracy would most likely increase greatly.

Conclusion

Air pressure was forecasted the most accurately as it is less affected by local weather patterns. Many of the AWS and forecast outputs were incorrectly calibrated for altitude, thus creating large AMPS biases.

The timing of a change in air temperature was forecasted within ±2hours, but the extent of this change was less accurately forecasted.

Overall wind velocity at any given time was forecasted accurately with ±4.3m/s, although no large wind event occurred during this time. The timing and forecasted wind strength of a large wind event is needed to further understand the accuracy of AMPS models.

To fully analyse the accuracy of AMPS the use of several years of data would be needed for the understanding of seasonal changes as well, as this study only covered 11 days. The correlation between more AWS observations, such as cloud cover, would further widen the accuracy analysis. The use of more AWS would also be crucial, especially for understanding the ability of AMPS to forecast local scale weather patterns.

Bromwich et al, 2005 undertook the same forecast accuracy analysis but over a two year period, there correlation coefficient results were low for many variables, as with this study. They also analysed the lower resolution 10km domain, where the correlation coefficients were far greater. This and other studies prove that the AMPS high resolution 1.7km domain still needs to be improved, but their current forecast ability is sufficient for the current operations undertaken around Ross Island.

Acknowledgments

Special thanks to Steve George (supervisor) for help, especially for extracting the necessary AMPS data needed. Thanks to Kevin Manning for supplying the necessary AMPS data.

References

AAWSP, Antarctic Automatic Weather Stations Project. Web site accessed 16th February 2010: http://amrc.ssec.wisc.edu/index.html

AMPS, The Antarctic Mesoscale Prediction System. Web site accessed 16th February 2010: http://www.mmm.ucar.edu/rt/wrf/amps/

Bromwich, D.H., Monaghan, A.J., Manning, K.W. & Powers, J.G. 2005, "Real-time forecasting for the Antarctic: An evaluation of the Antarctic Mesoscale Prediction System (AMPS)", *Monthly Weather Review,* vol. 133, no. 3, pp. 579-603.

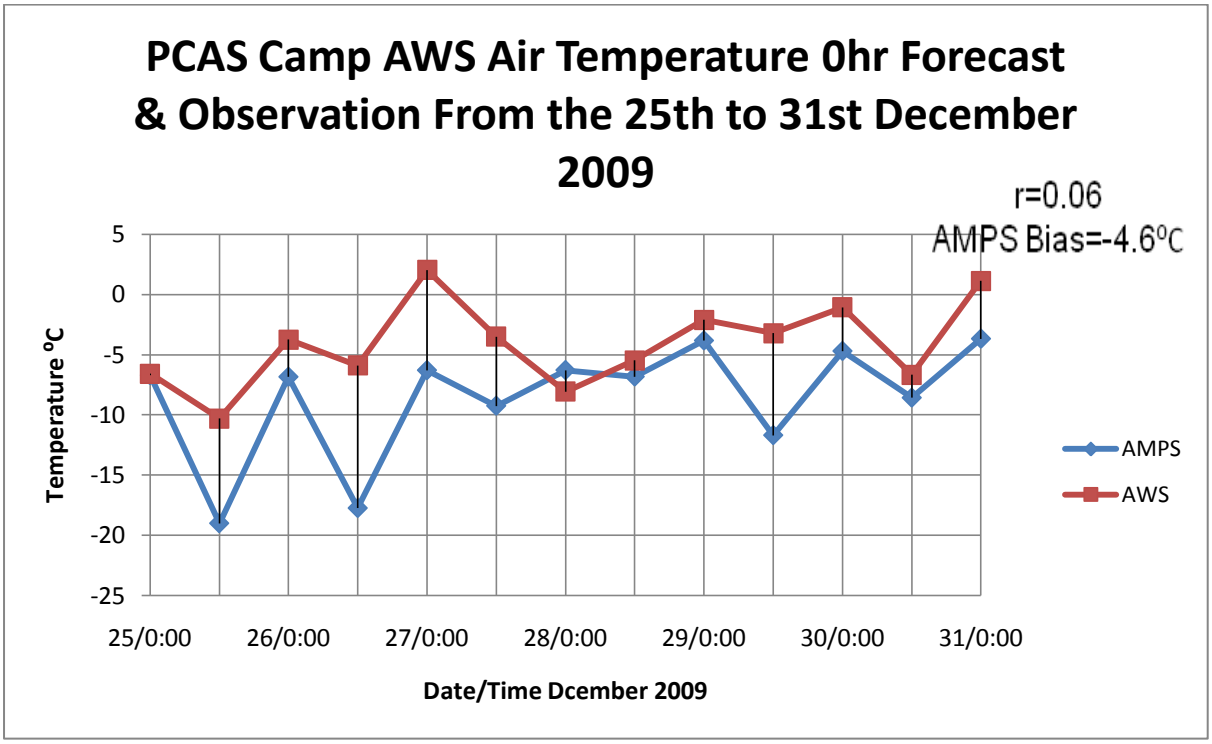
Bromwich, D.H. 1991, "Mesoscale cyclogenesis over the southwestern Ross Sea linked to strong katabatic winds", *Monthly Weather Review,* vol. 119, no. 7, pp. 1736-1752.

O'Connor, W.P., Bromwich, D.H. & Carrasco, J.F. 1994, "Cyclonically forced barrier winds along the Transantarctic Mountains near Ross Island", *Monthly Weather Review,* vol. 122, no. 1, pp. 137-150.

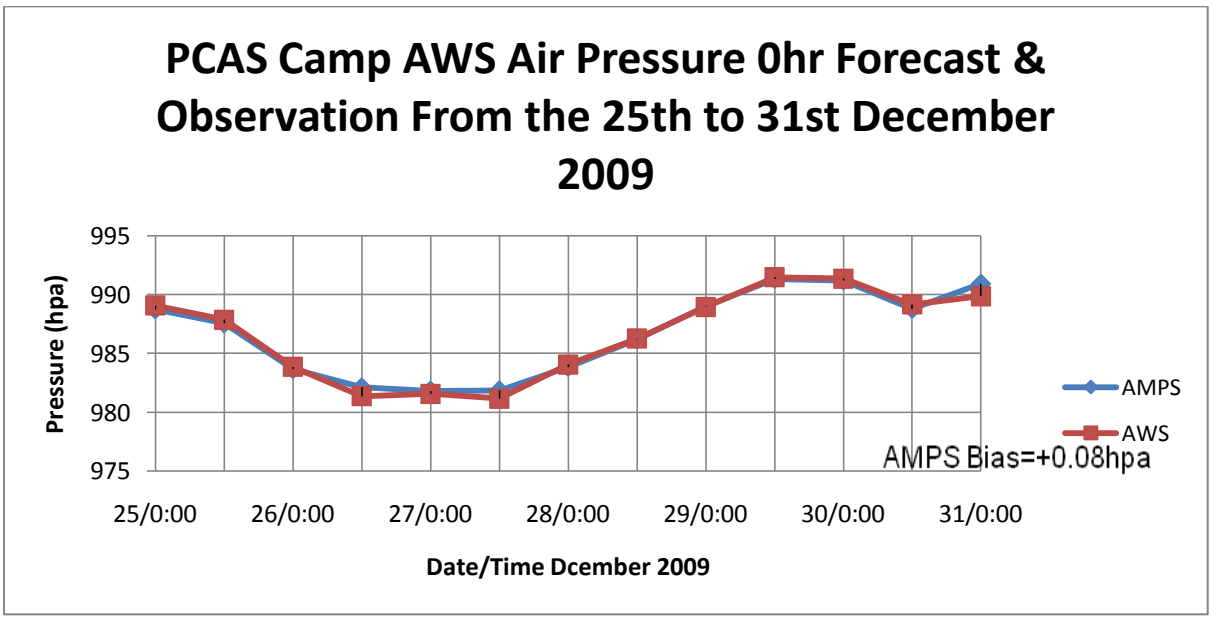
Appendices

Appendix 1: PCAS Camp AWS (HOBO) observation and corresponding forecasts.

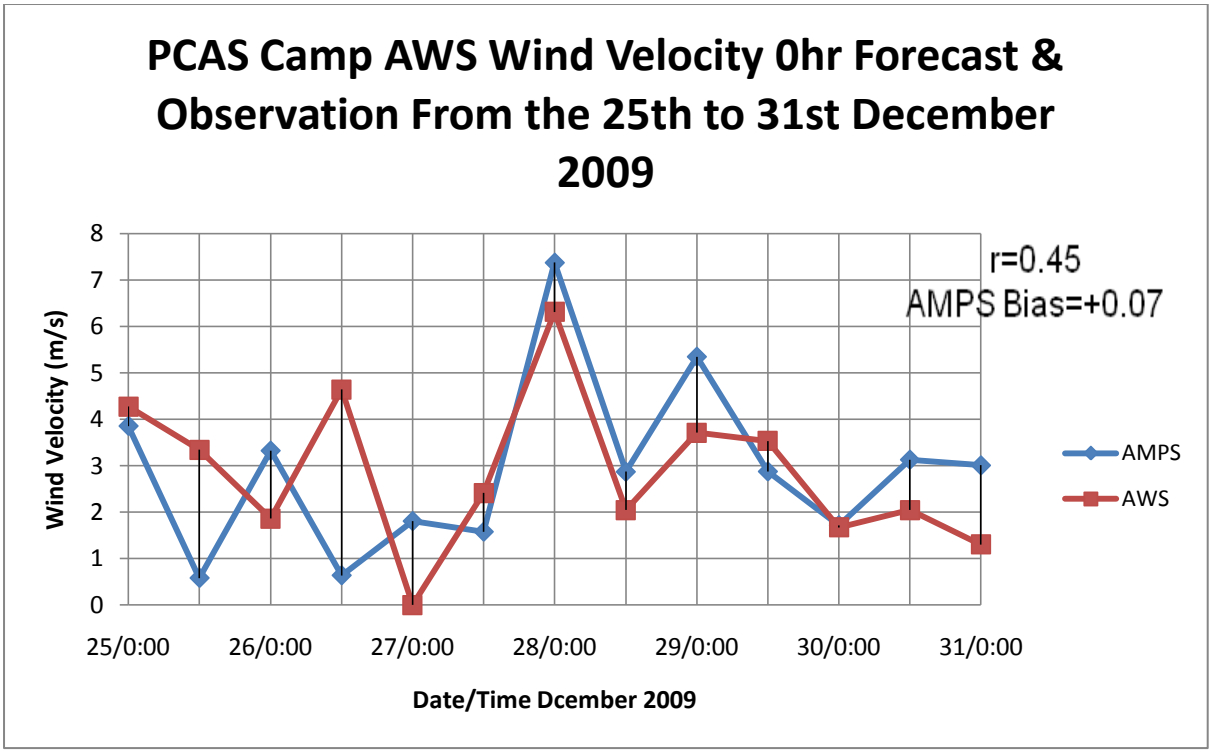
1A) AMPS 0hr forecast, i.e. analysis of the current weather conditions for a given day. Forecasted every 12 hours from 25th to 31st December 2009.



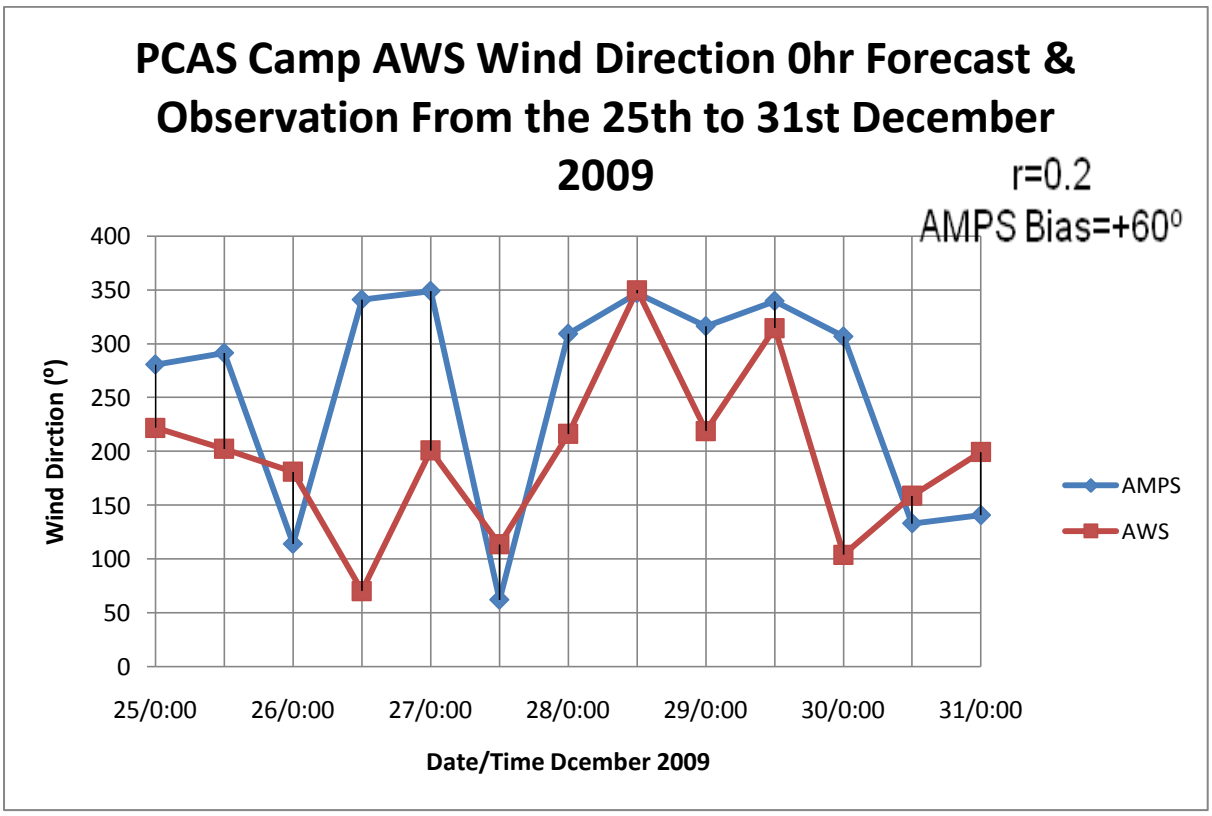
1Ai) Air temperature



1Aii) Air Pressure

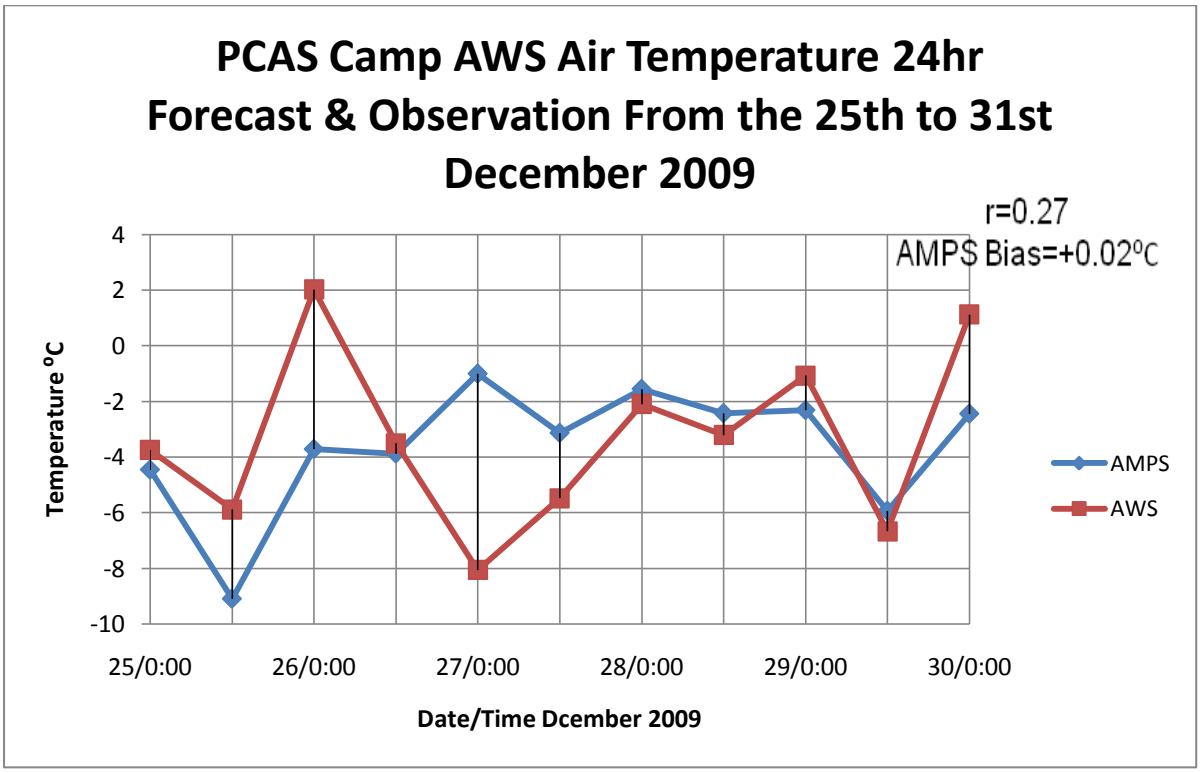


1Aiii) Wind Velocity

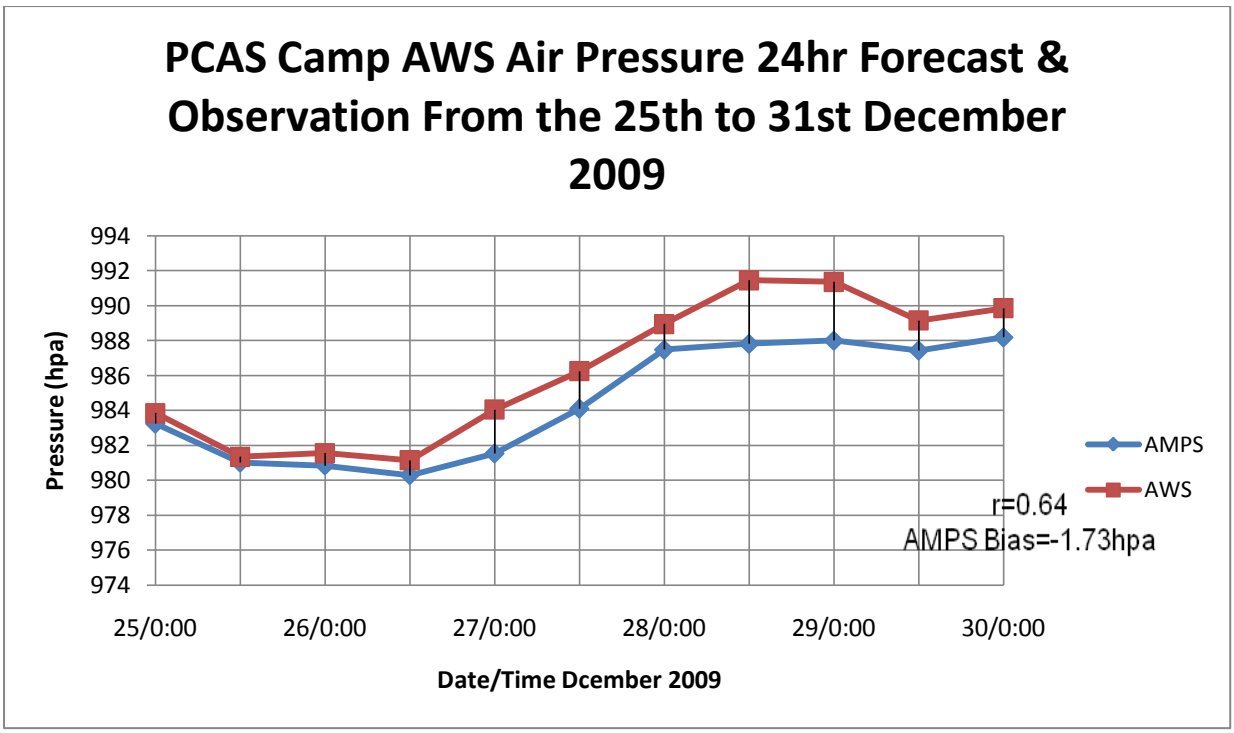


1Aiv) Wind Direction

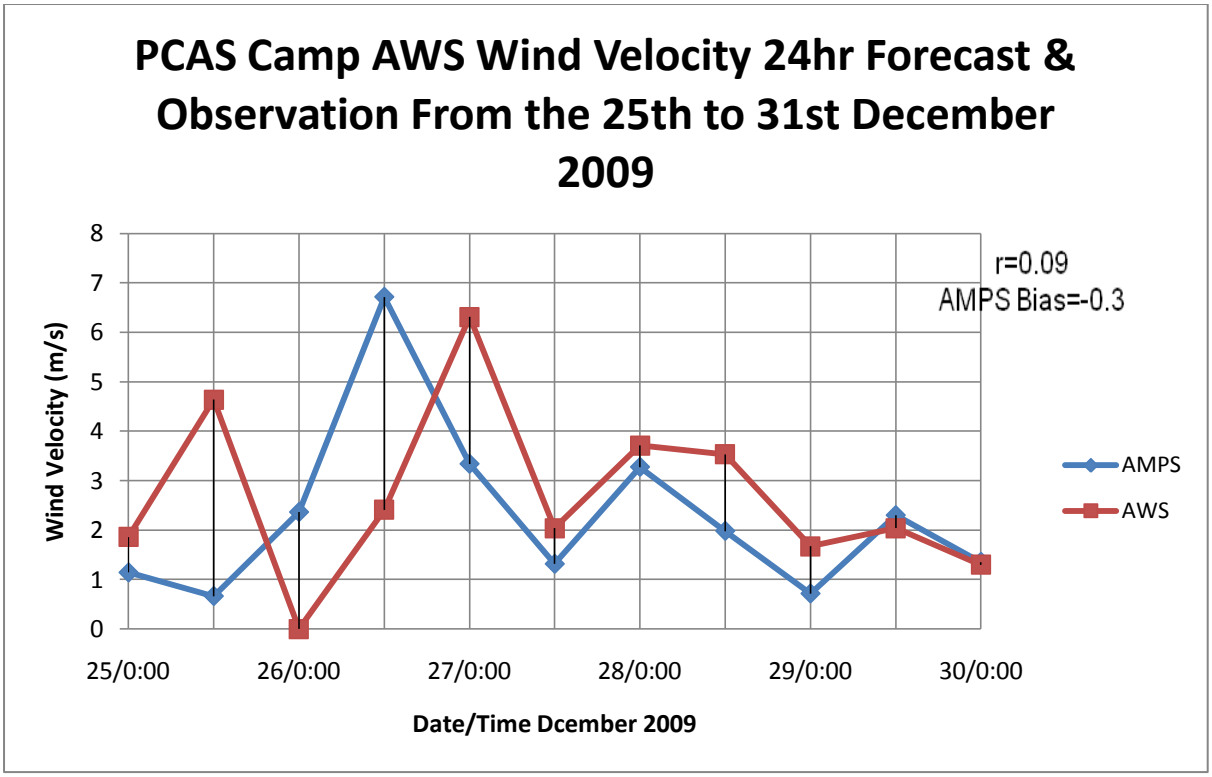
1B) AMPS 24 hour forecast and AWS observation corresponding to this forecast. Forecasted every 12 hours from the 25th to 31st December 2009.



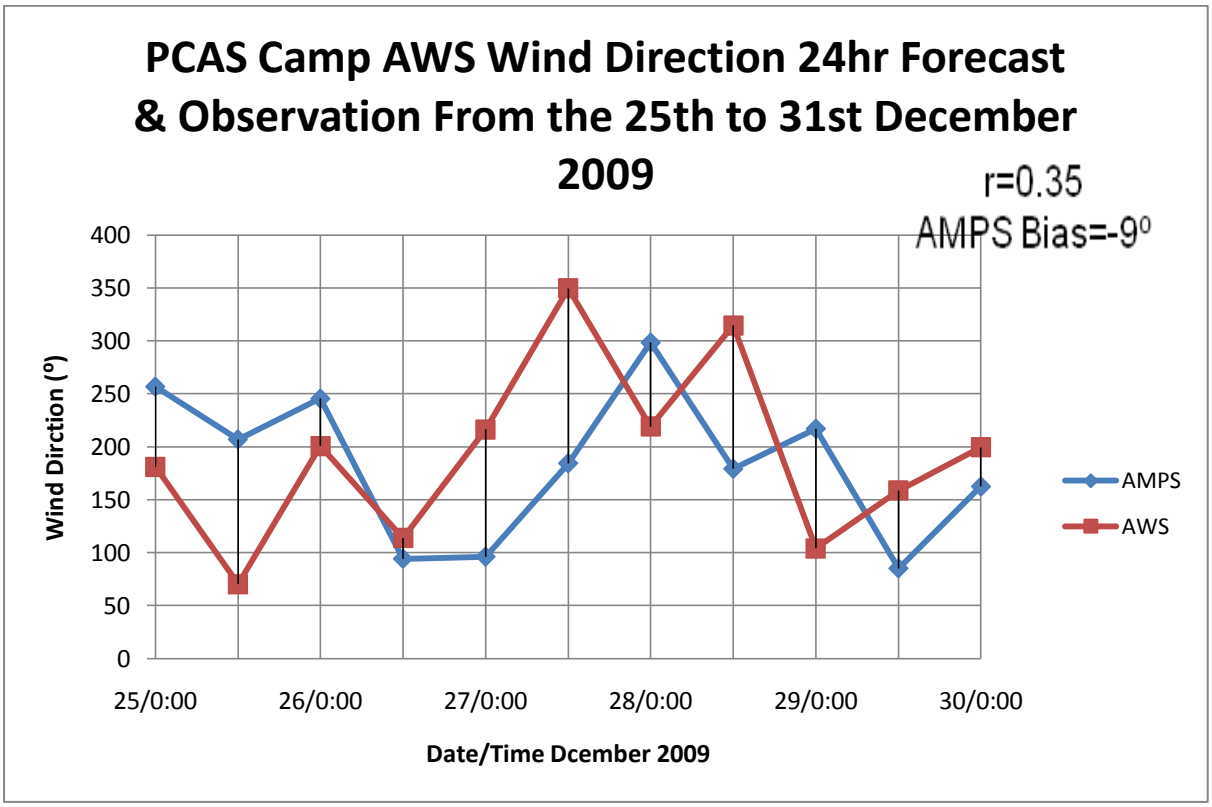
1Bi) *(Above)* Air Temperature



1Bii) Air Pressure

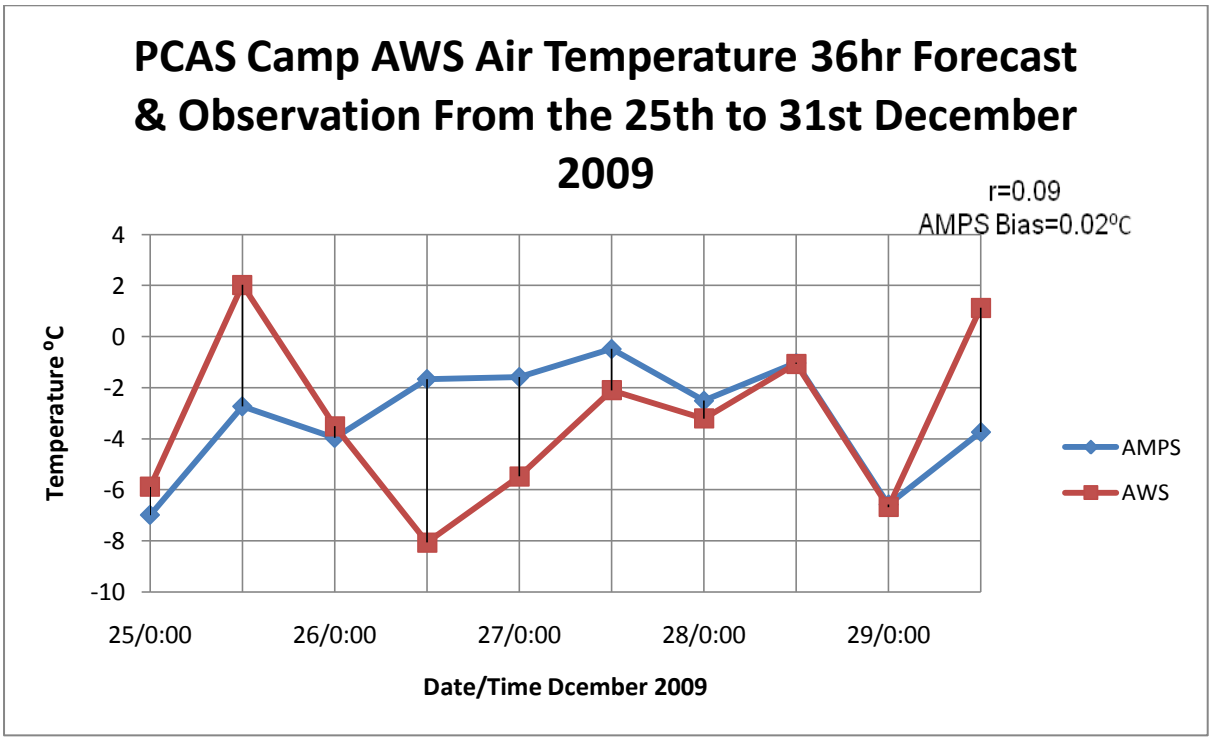


1Biii) Wind Velocity

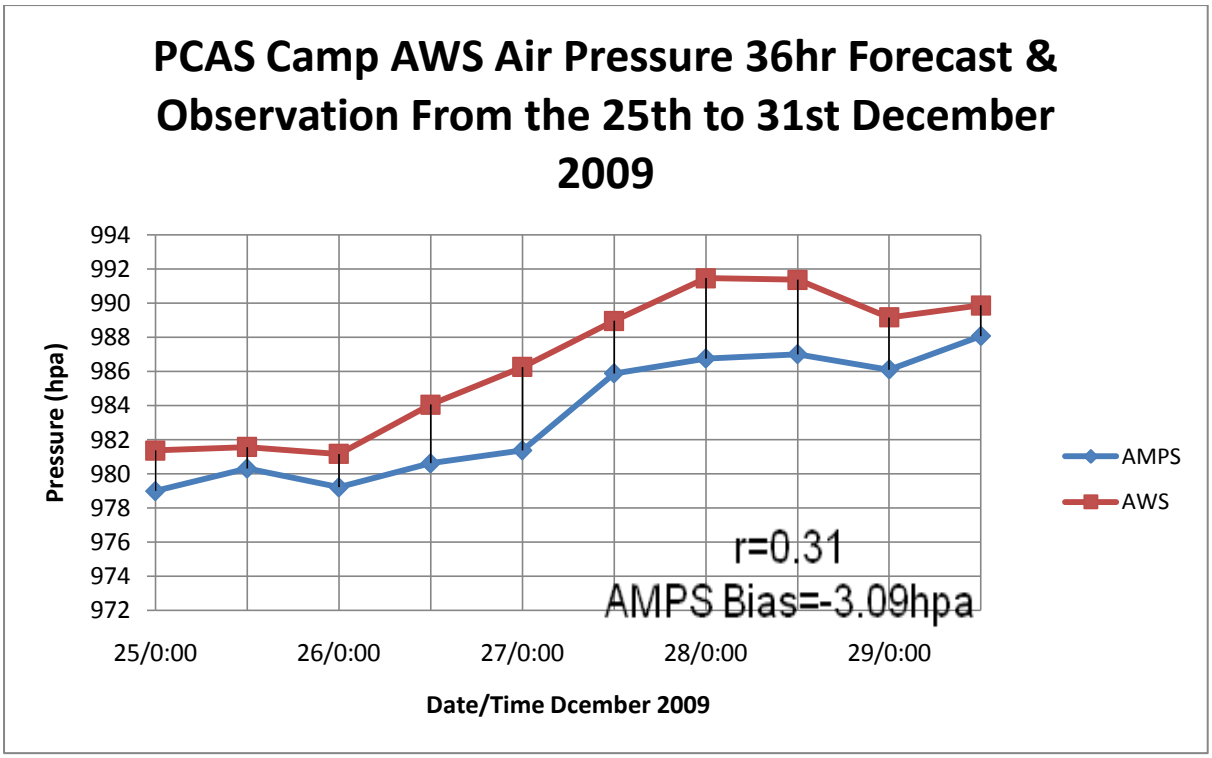


1Biv) Wind Direction

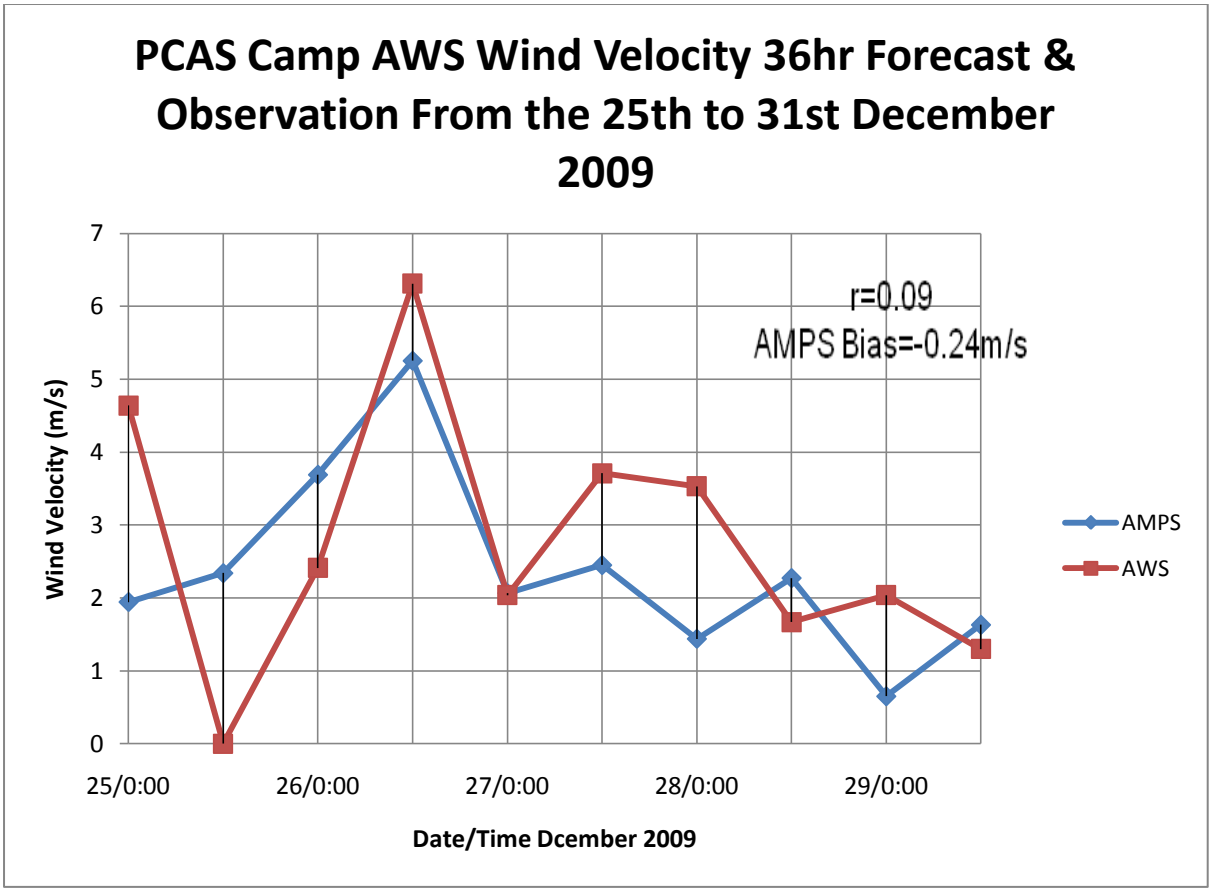
1C) AMPS 36 hour forecast and AWS observation corresponding to this forecast. Forecasted every 12 hours from the 25th to 31st December 2009.



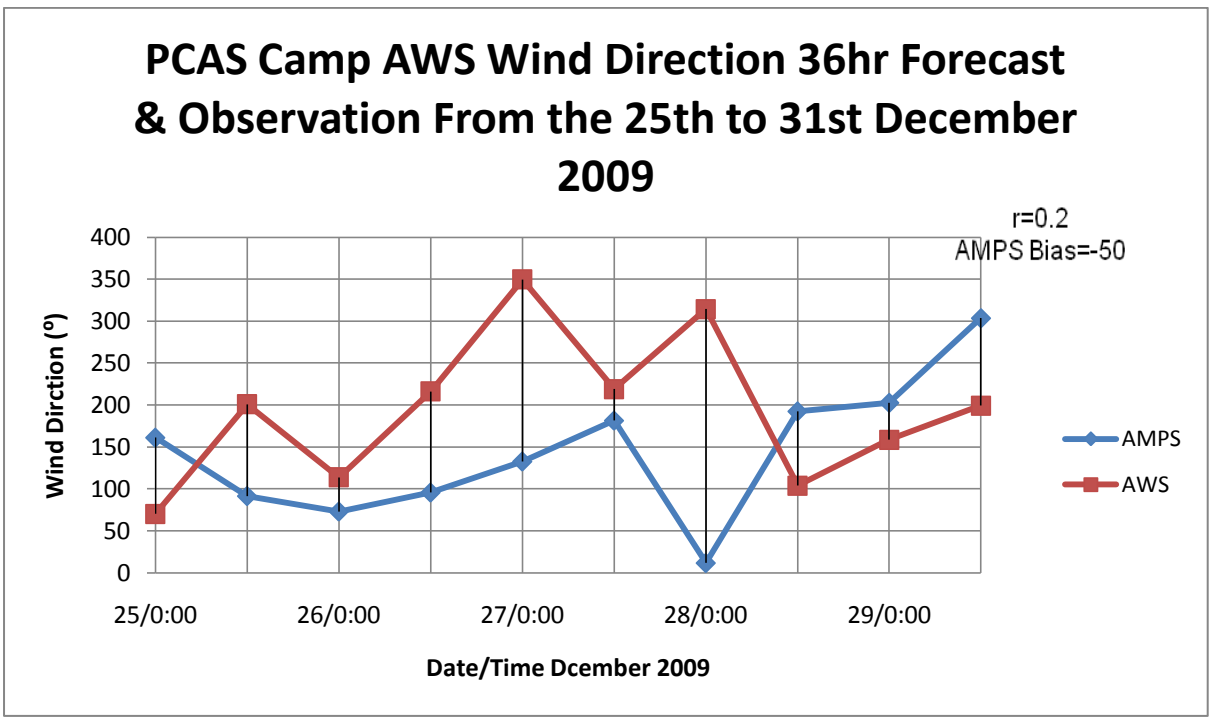
1Ci) Air Temperature



1Cii) Air Pressure



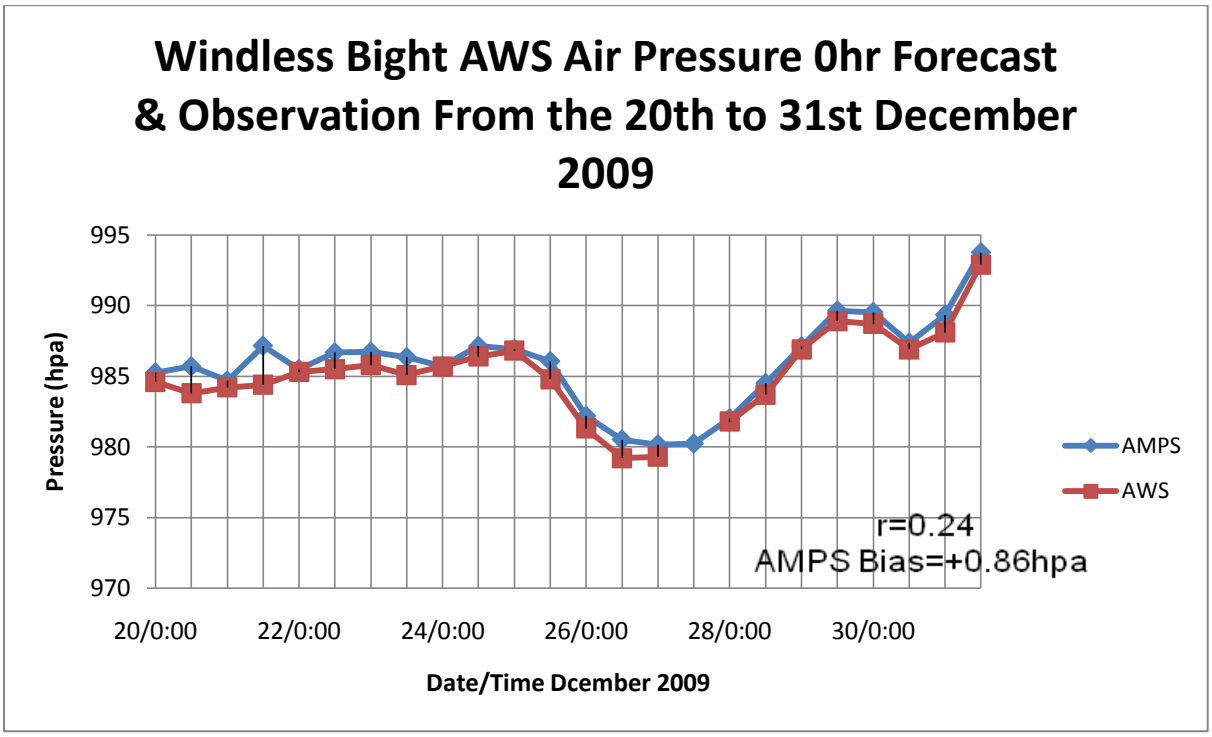
1Ciii) Wind Velocity



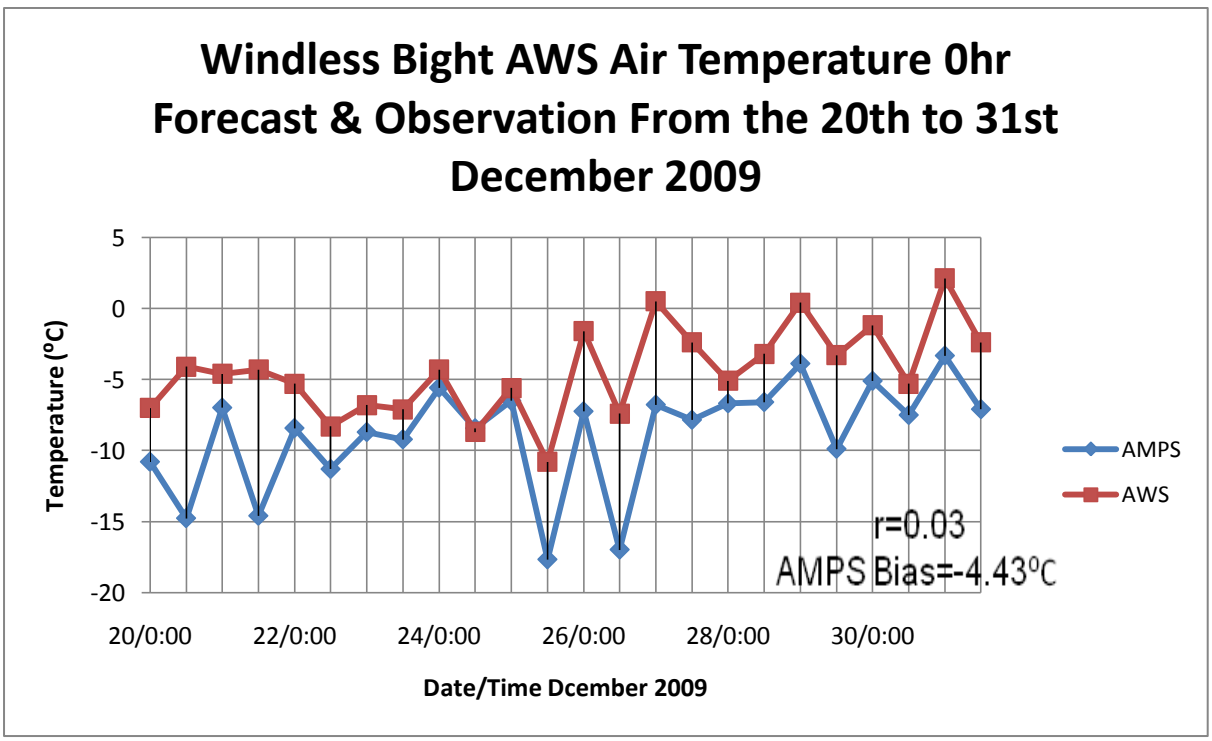
1Civ) Wind Direction

Appendix 2: Windless Bight AWS observations and corresponding forecasts.

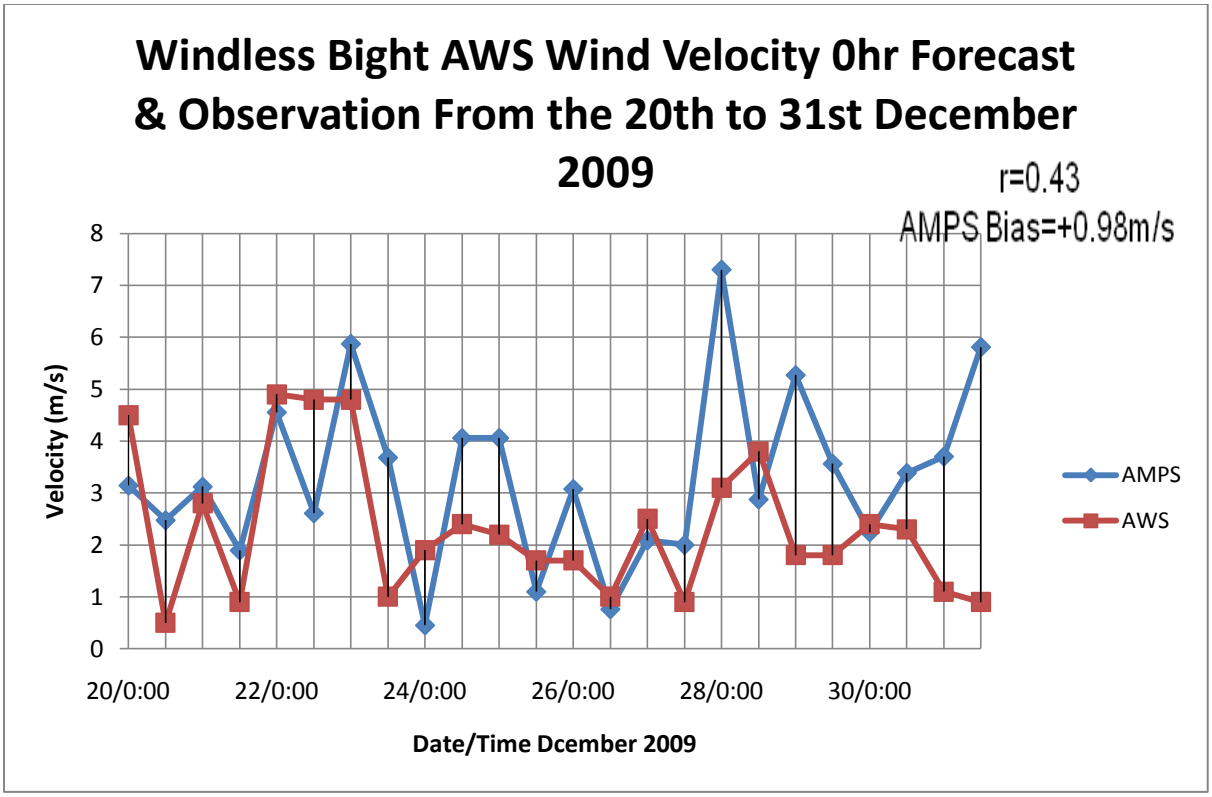
2A) AMPS 0 hour forecasts. Forecasted every 12 hours from 25th to 31st December 2009.



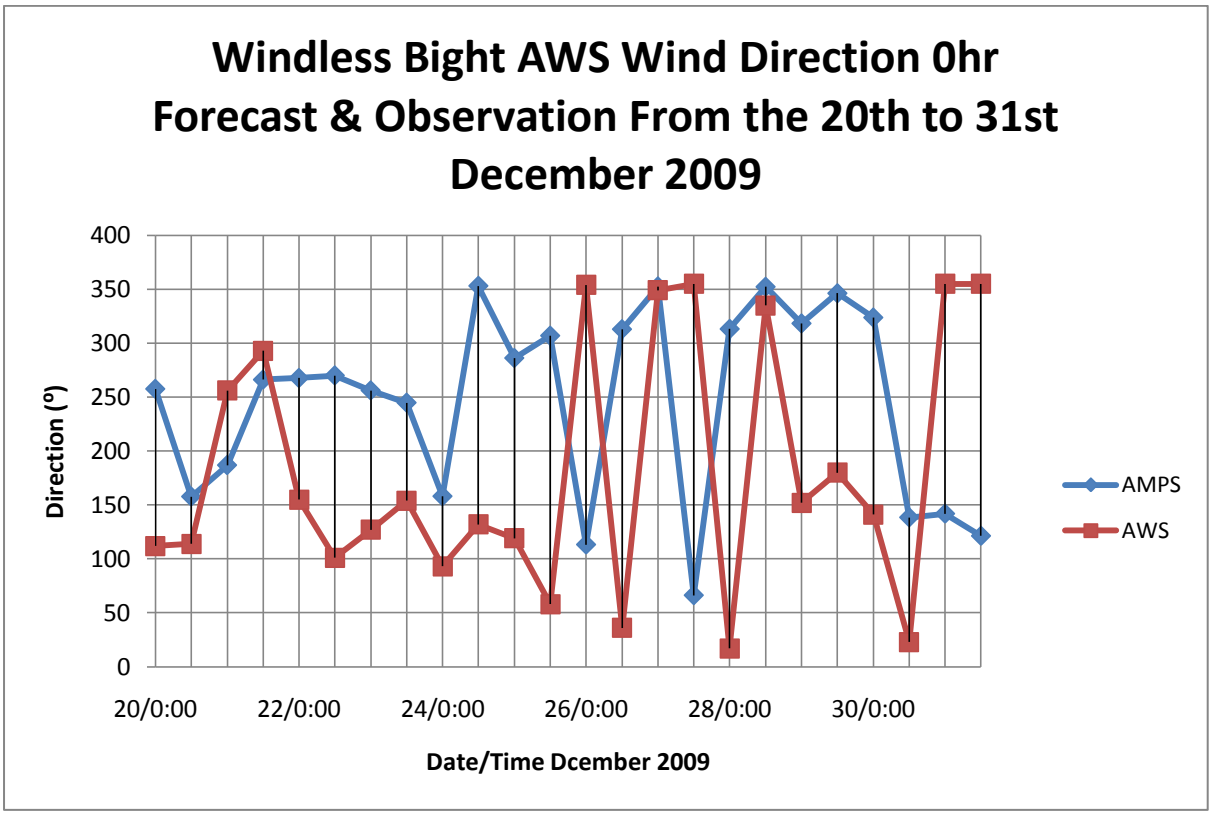
2Ai) Air Pressure



2Aii) Air Temperature

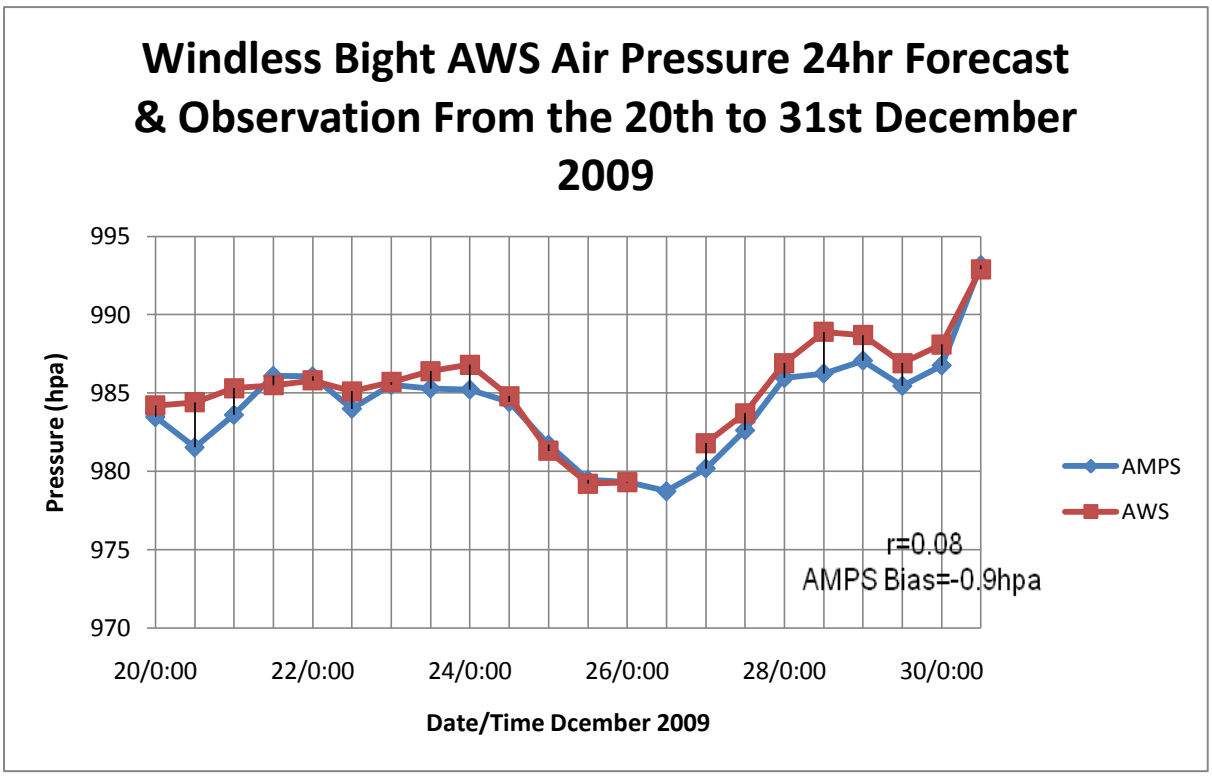


2Aiii) Wind Velocity

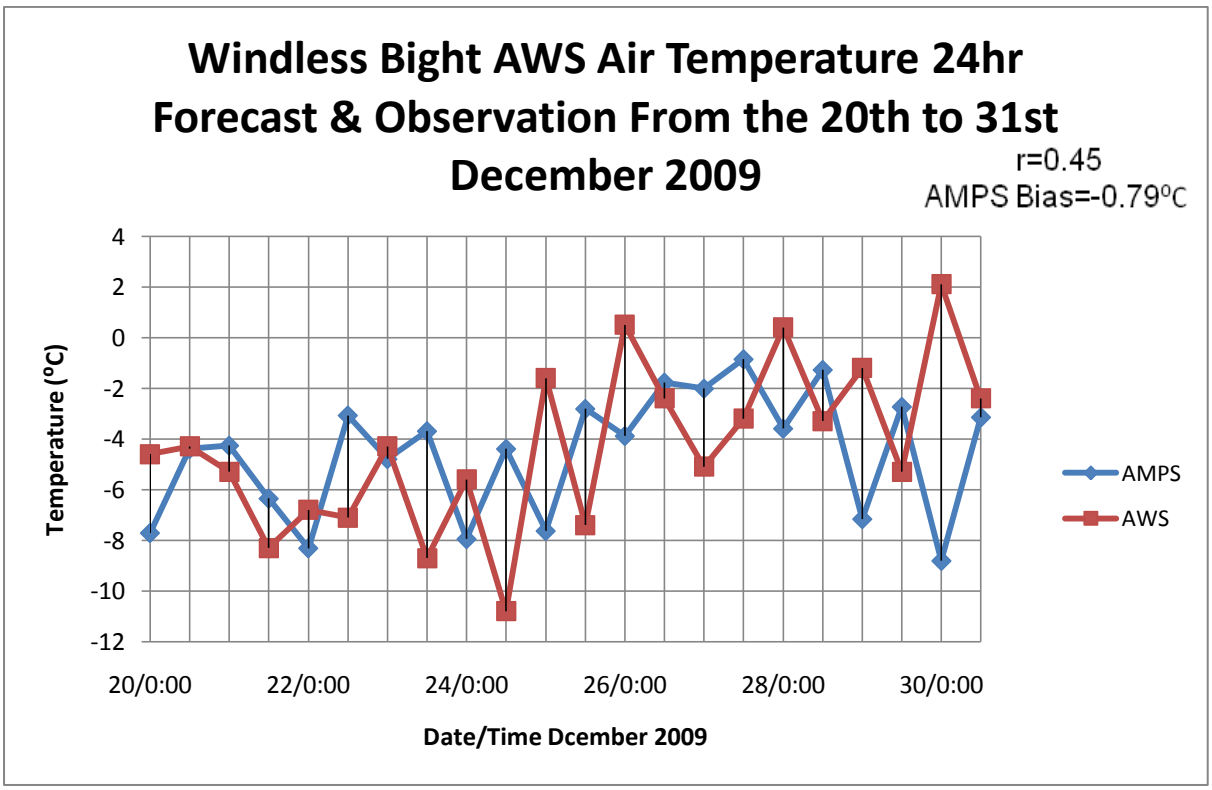


2Aiv) Wind Direction

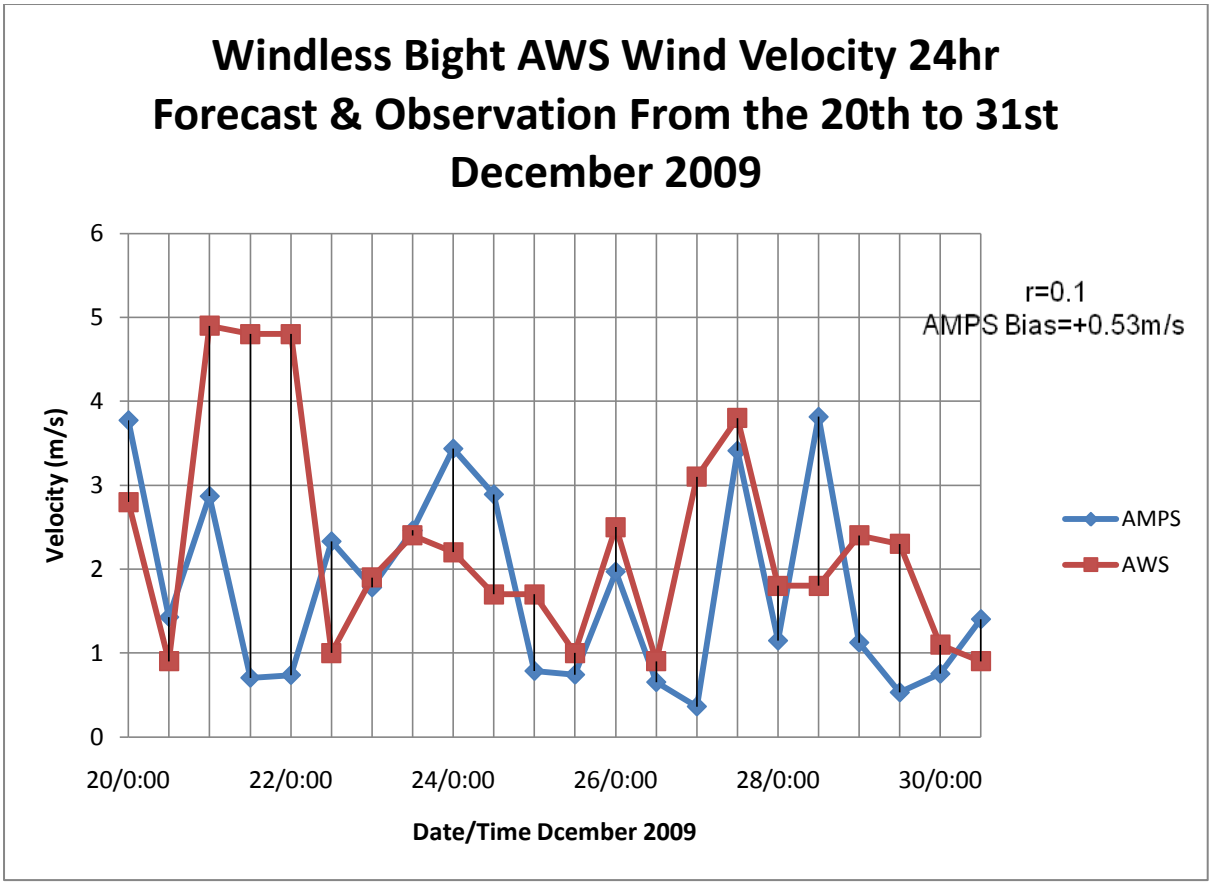
2B) AMPS 24 hour forecasts. Forecasted every 12 hours from 25th to 31st December 2009.



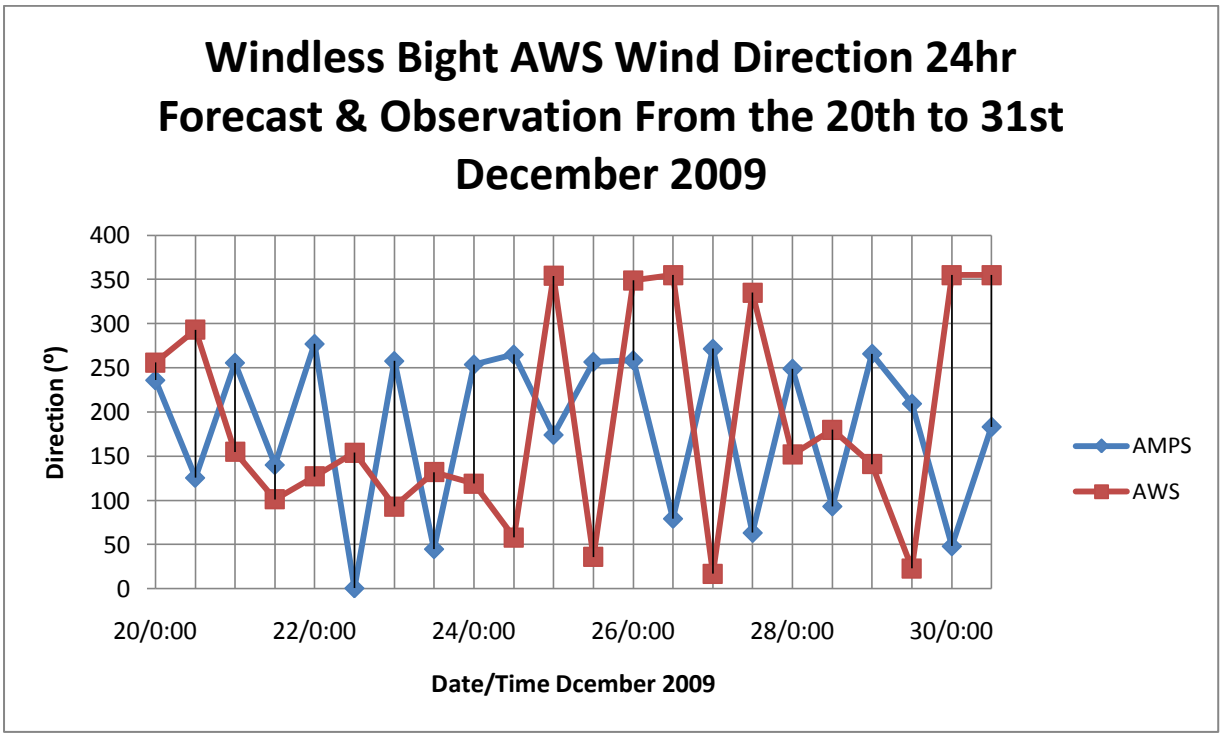
2Bi) Air Pressure



2Bii) Air Temperature

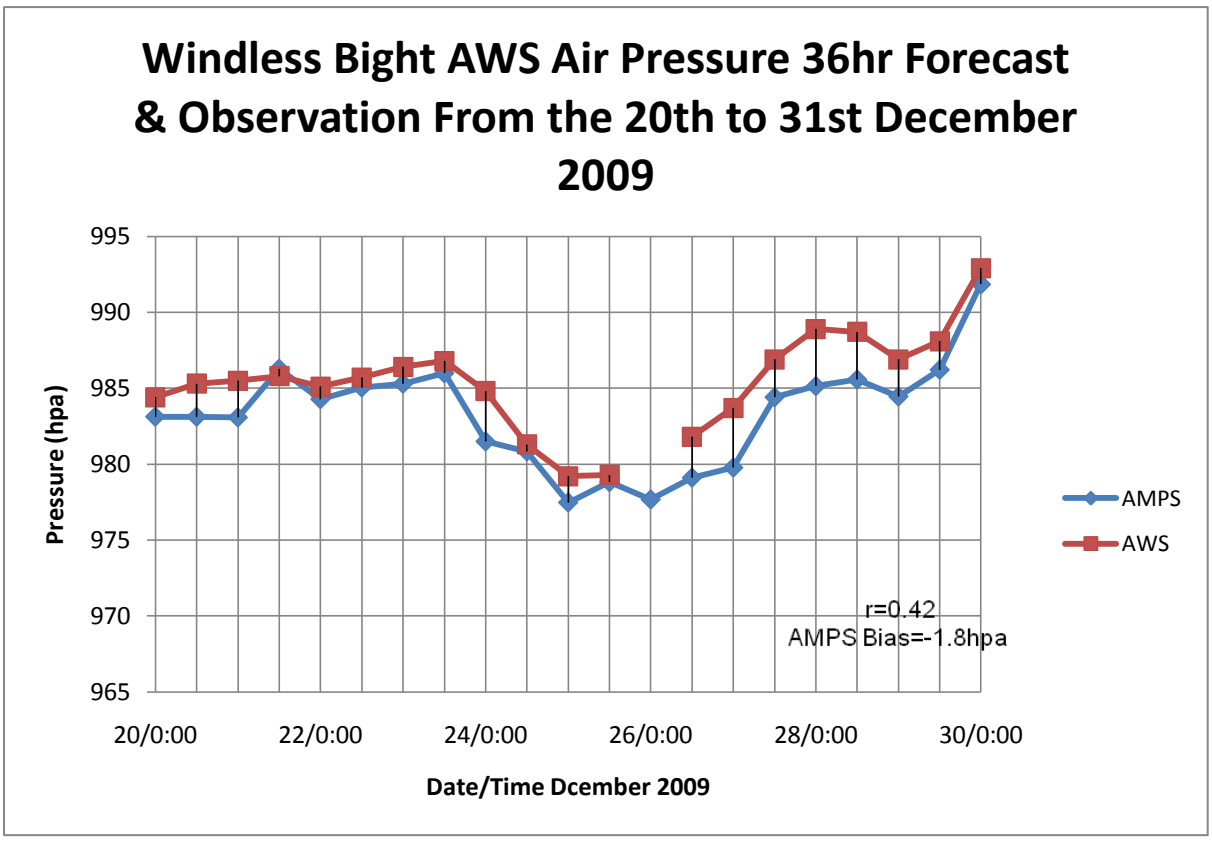


2Biii) Wind Velocity

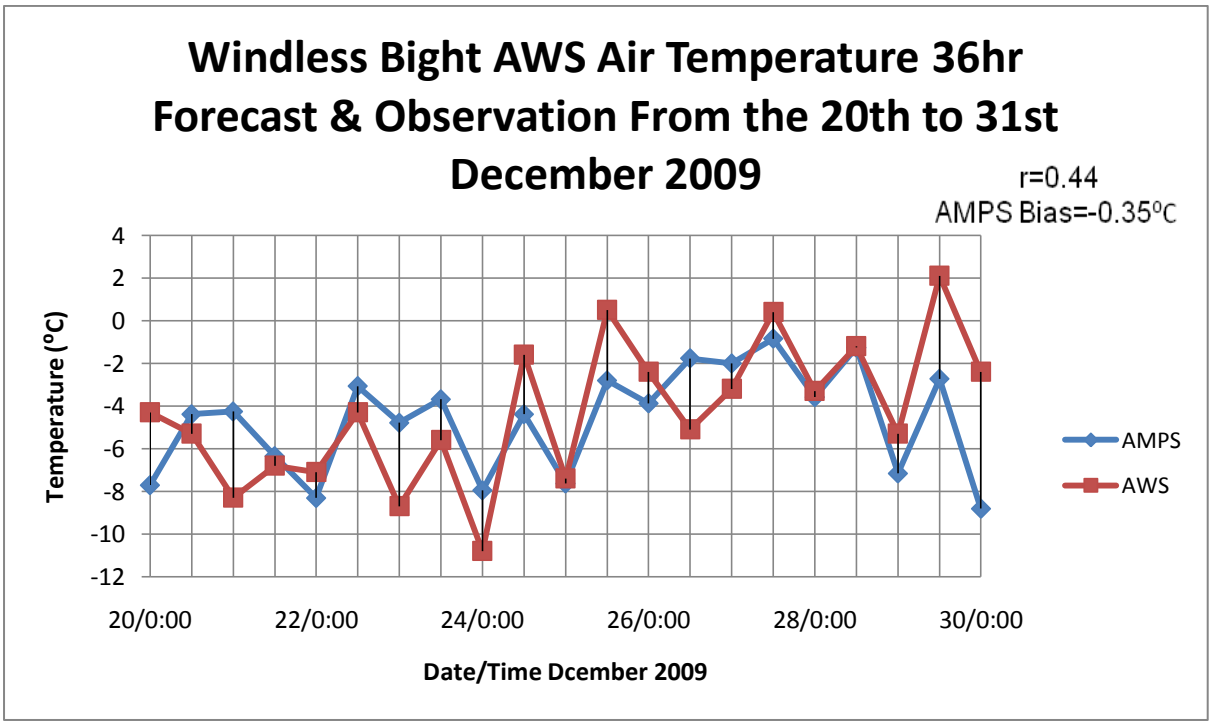


2Biv) Wind Direction

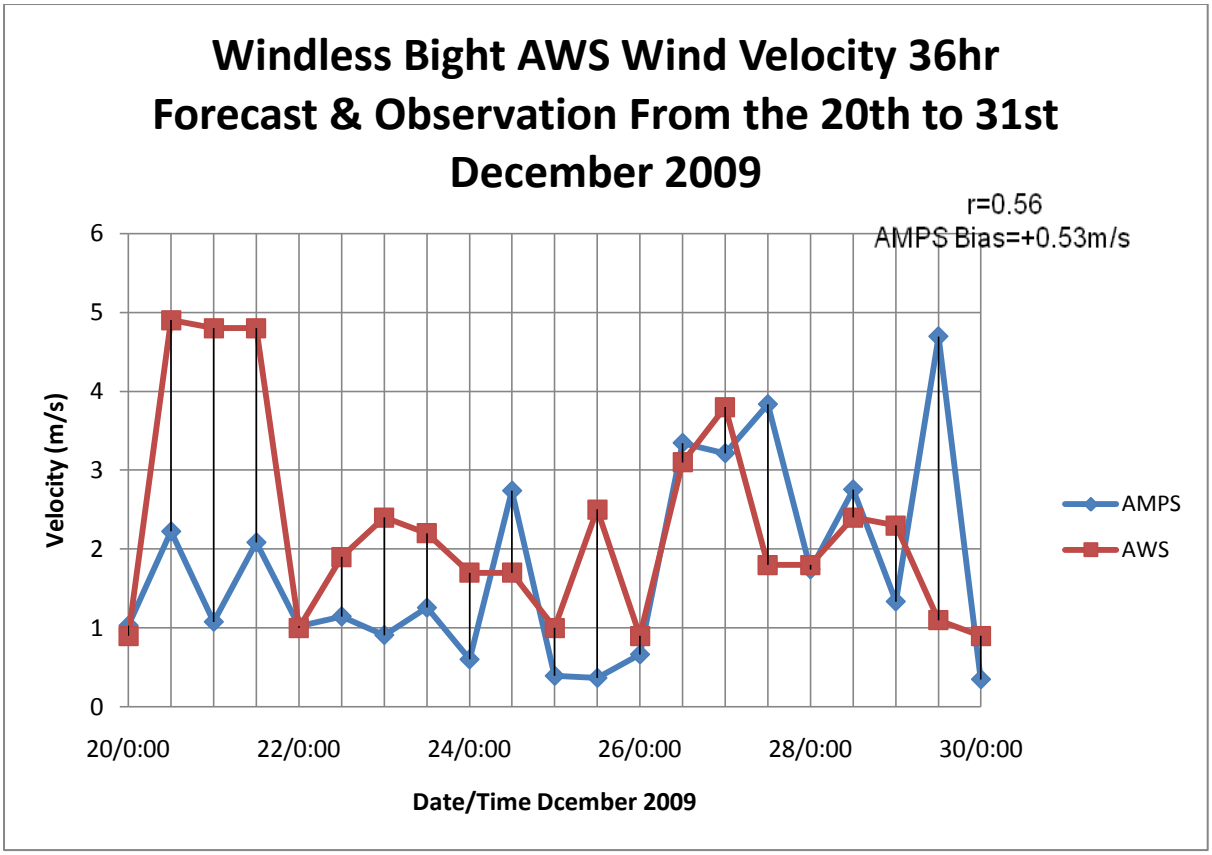
2C) AMPS 36 hour forecasts. Forecasted every 12 hours from 25th to 31st December 2009



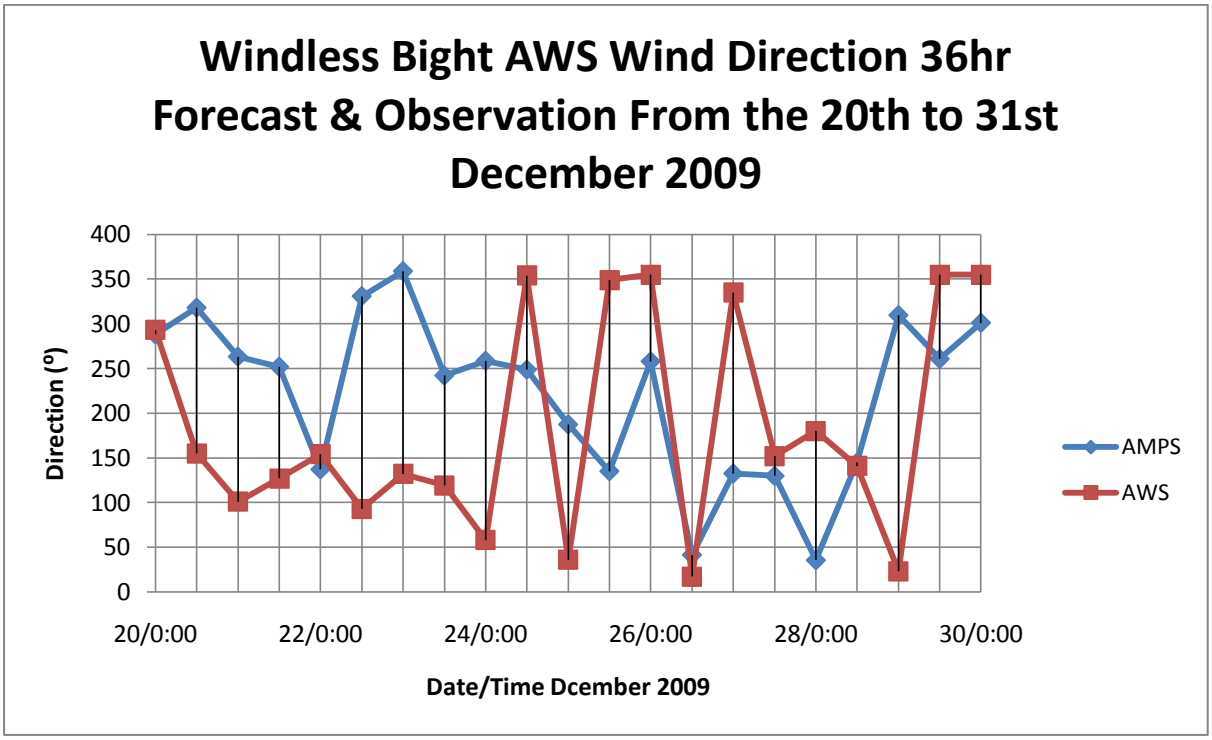
2Ci) Air Pressure



2Cii) Air Temperature



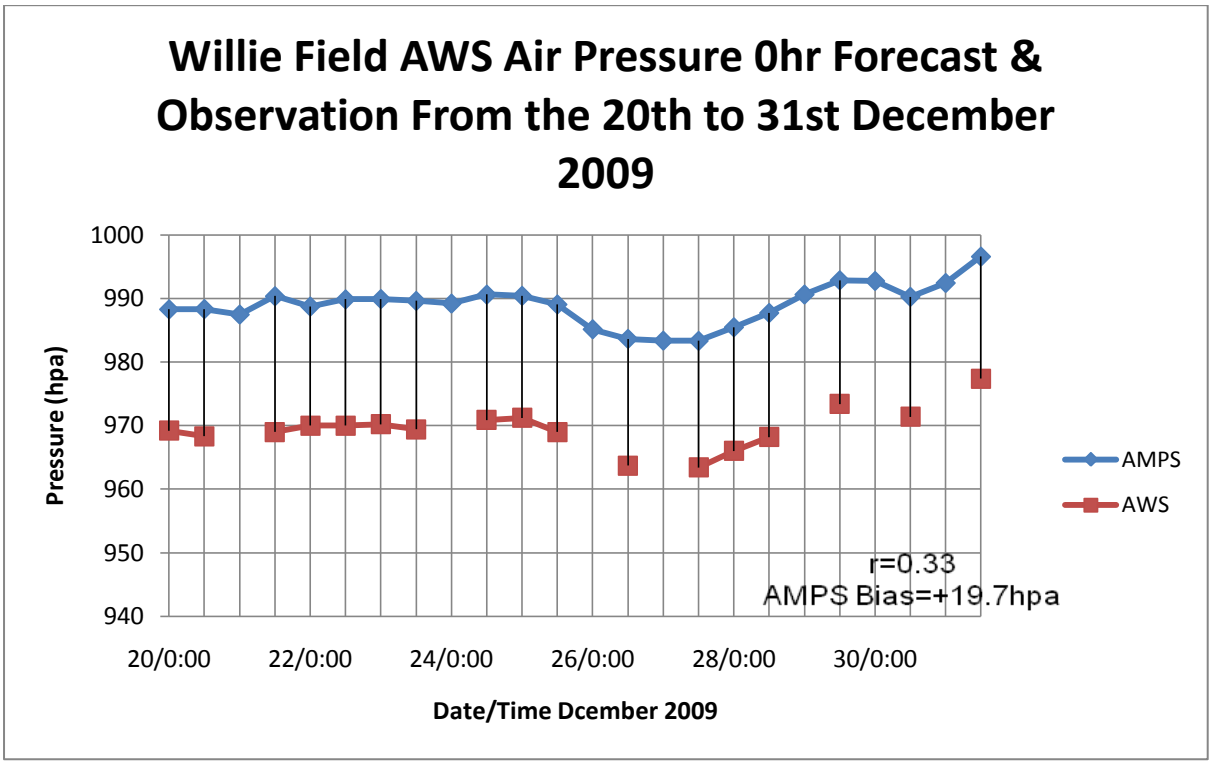
2Ciii**)** Wind Velocity



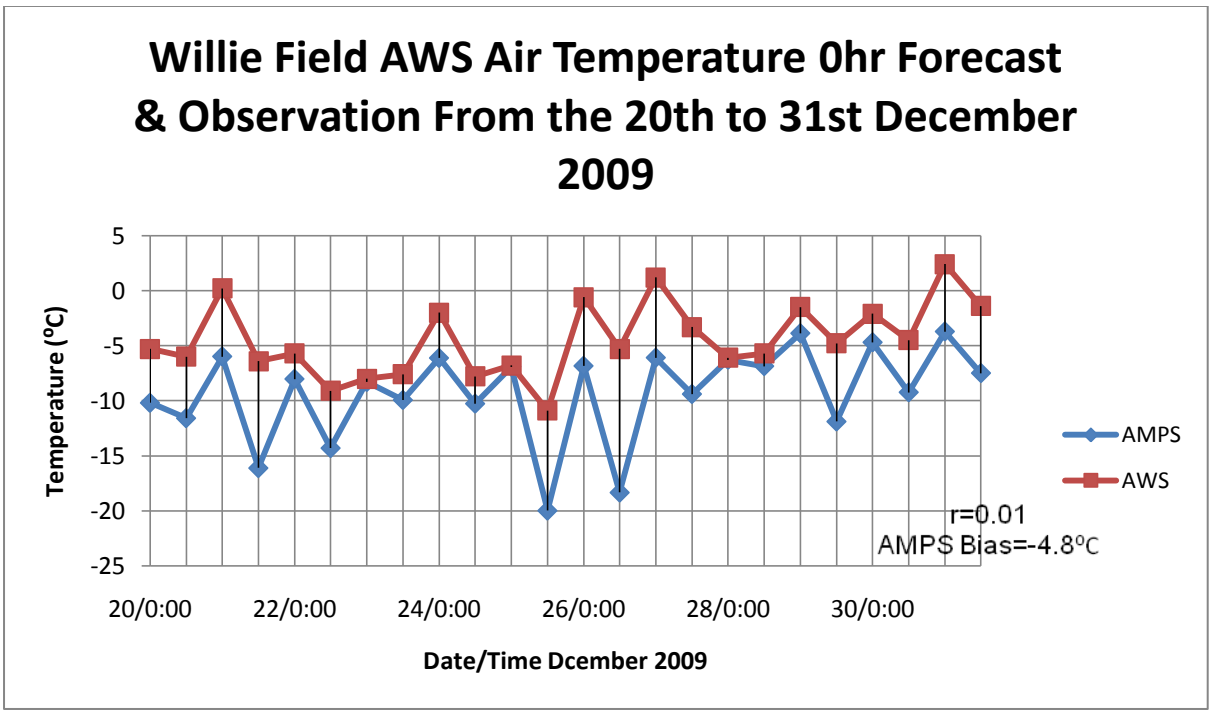
2Civ**)** Wind Direction

Appendix 3: Willie Field AWS observations and corresponding forecasts.

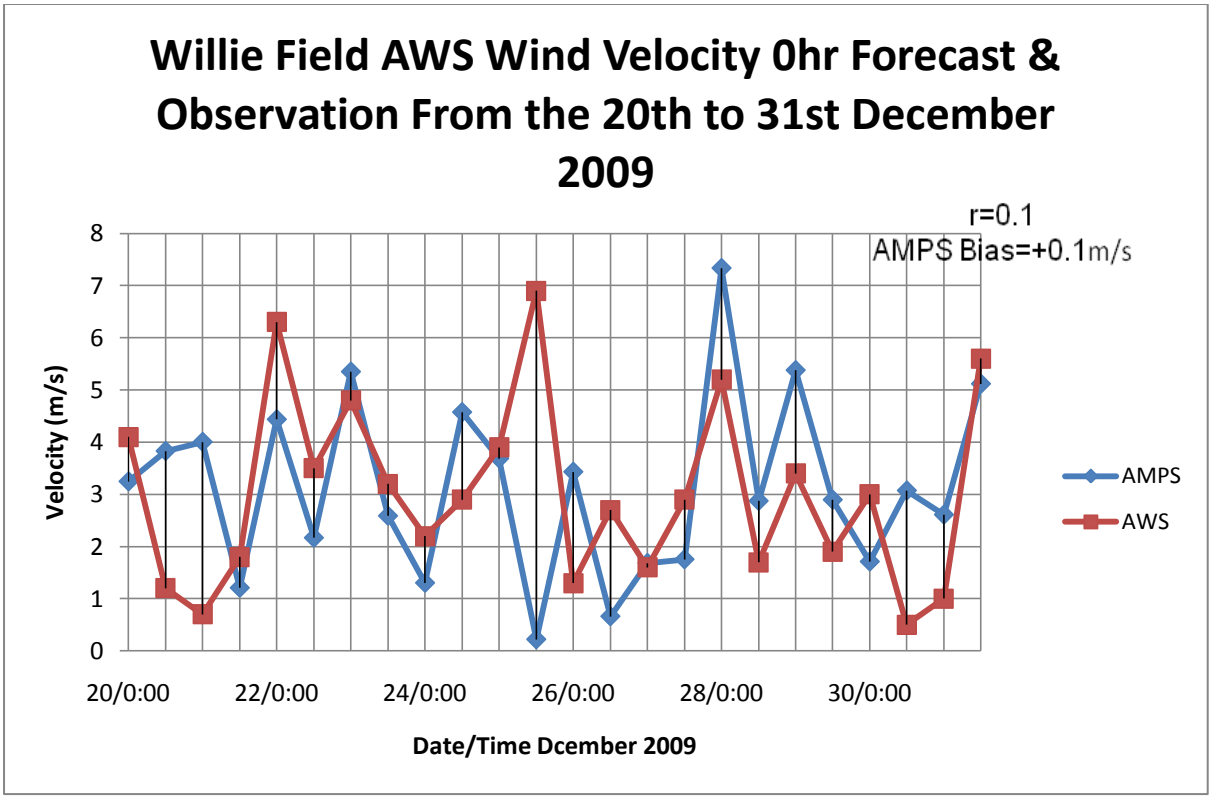
3A) AMPS 0 hour forecasts. Forecasted every 12 hours from 25th to 31st December 2009.



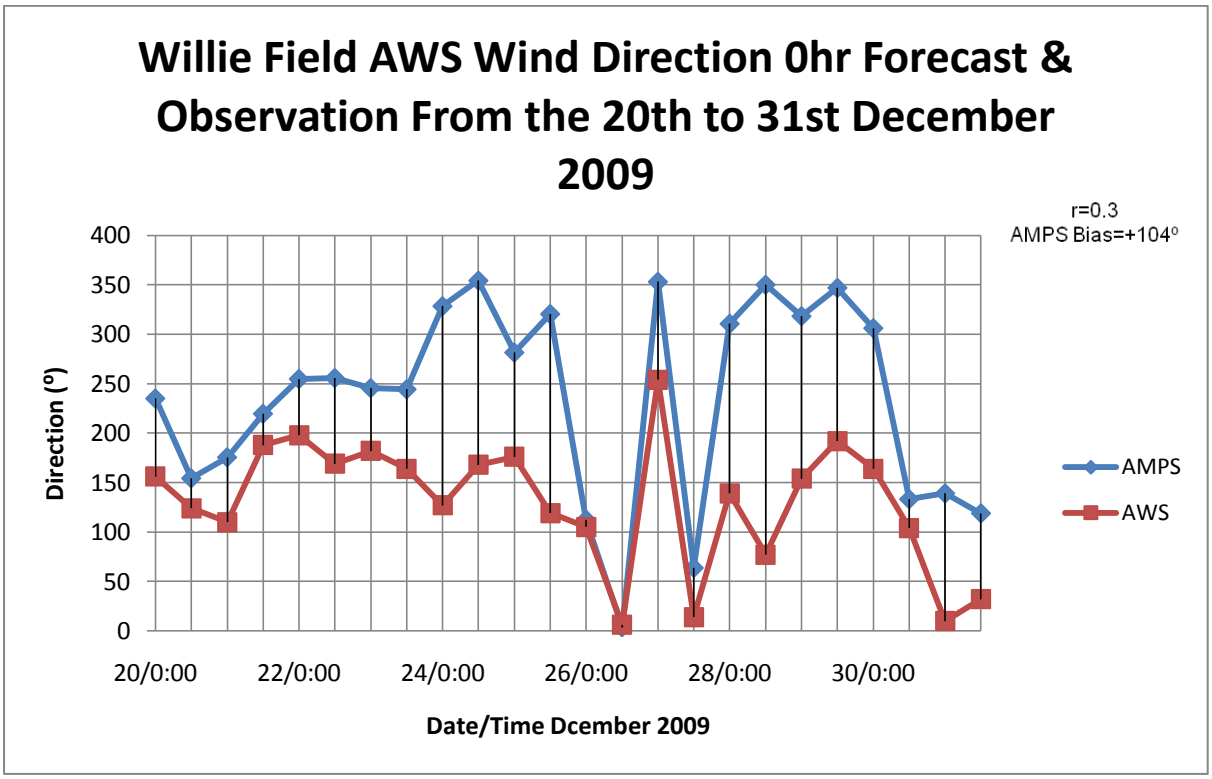
3Ai) Air Pressure



3Aii) Air Temperature

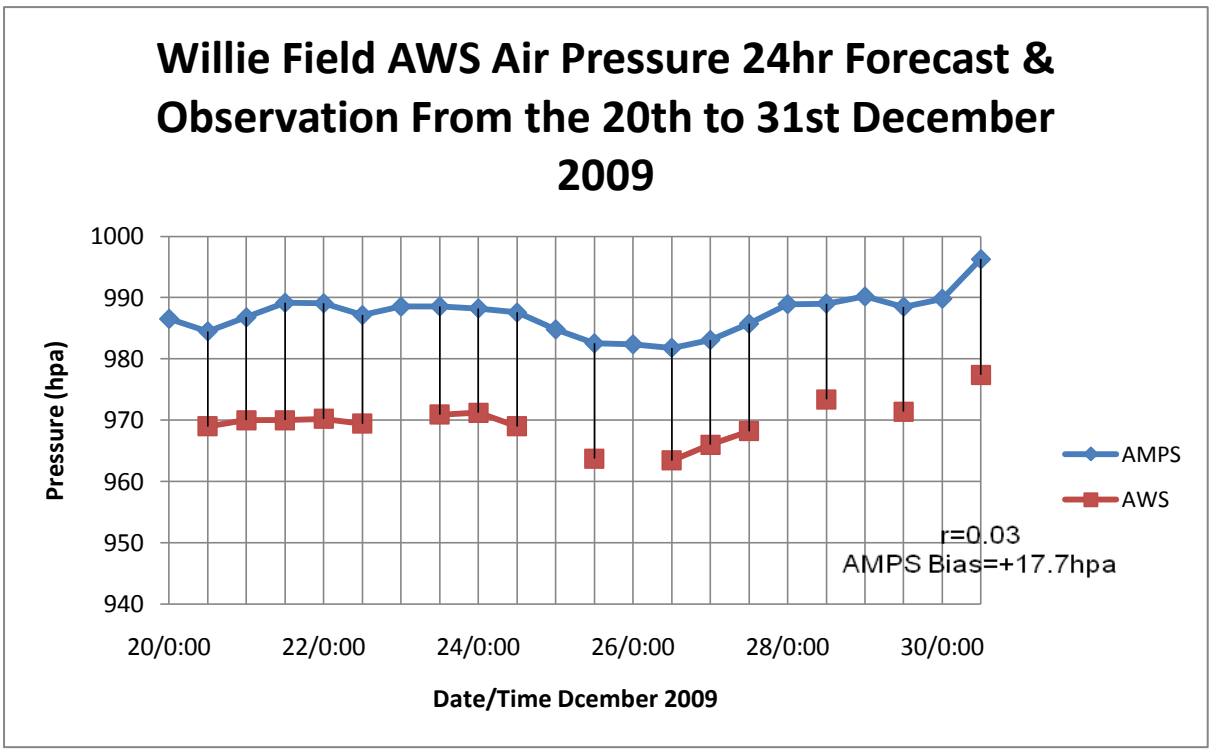


3Aiii) Wind Velocity

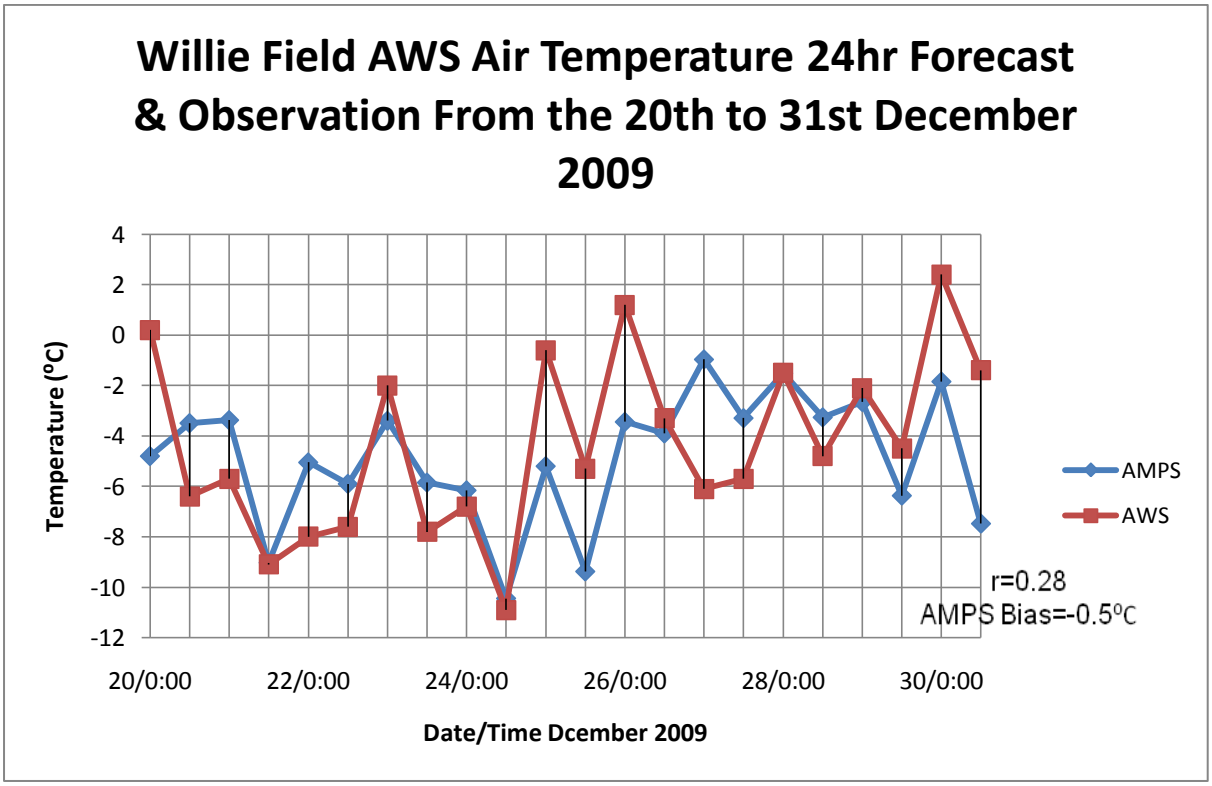


3Aiv) Wind Direction

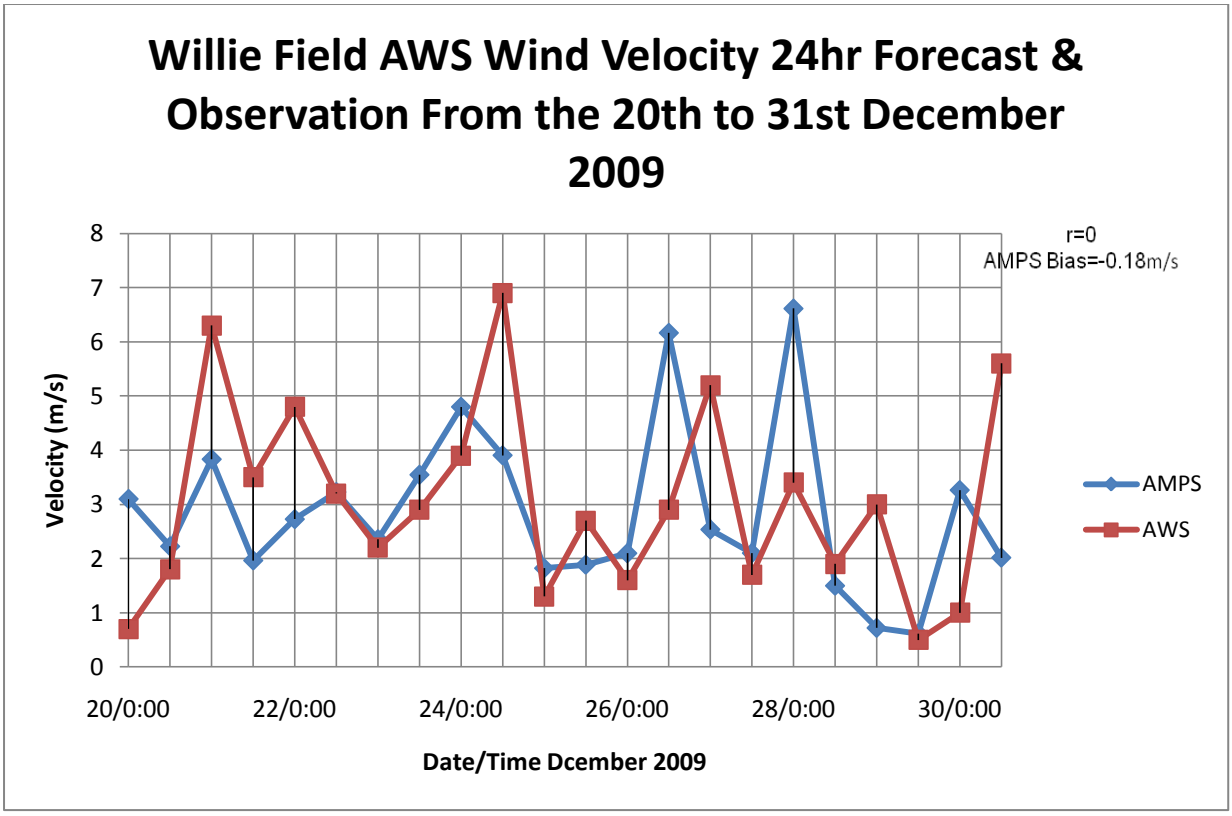
3B) AMPS 24 hour forecasts. Forecasted every 12 hours from 25th to 31st December 2009.



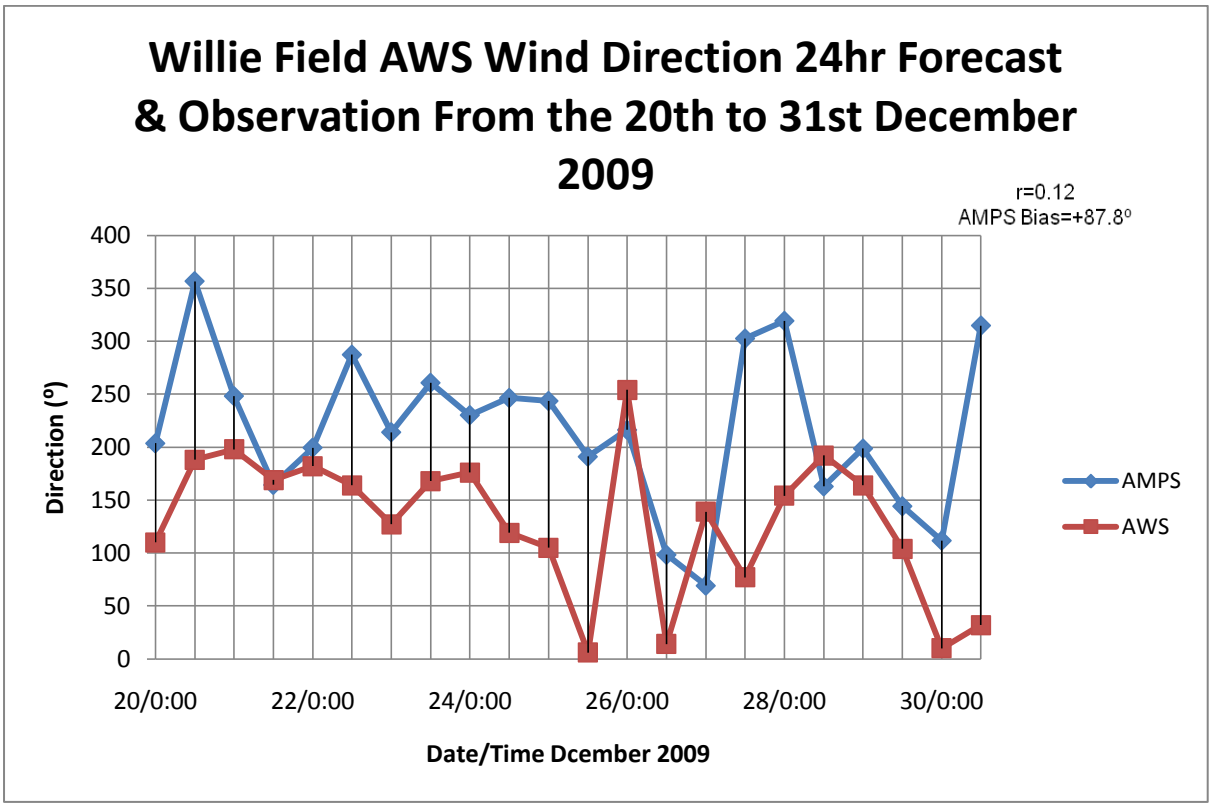
3Bi) Air Pressure



3Bii) Air Temperature

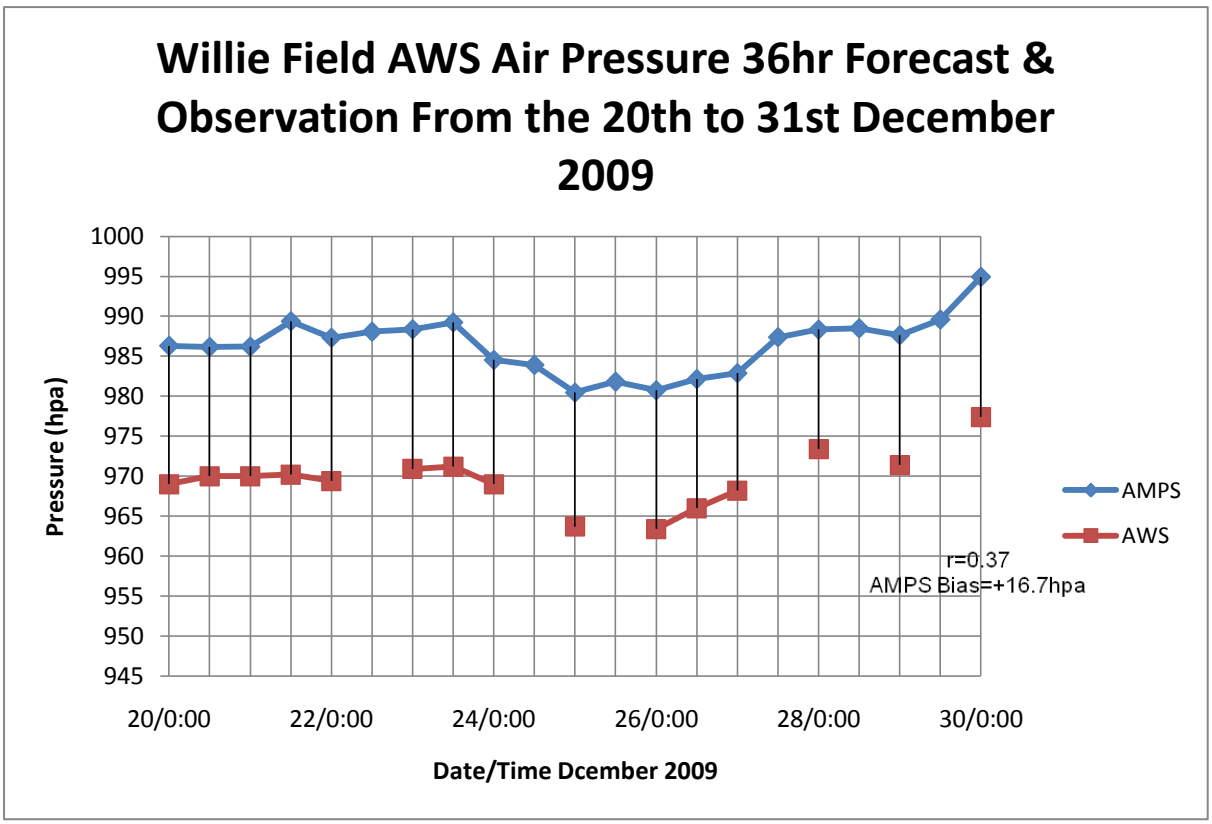


3Biii) Wind Velocity

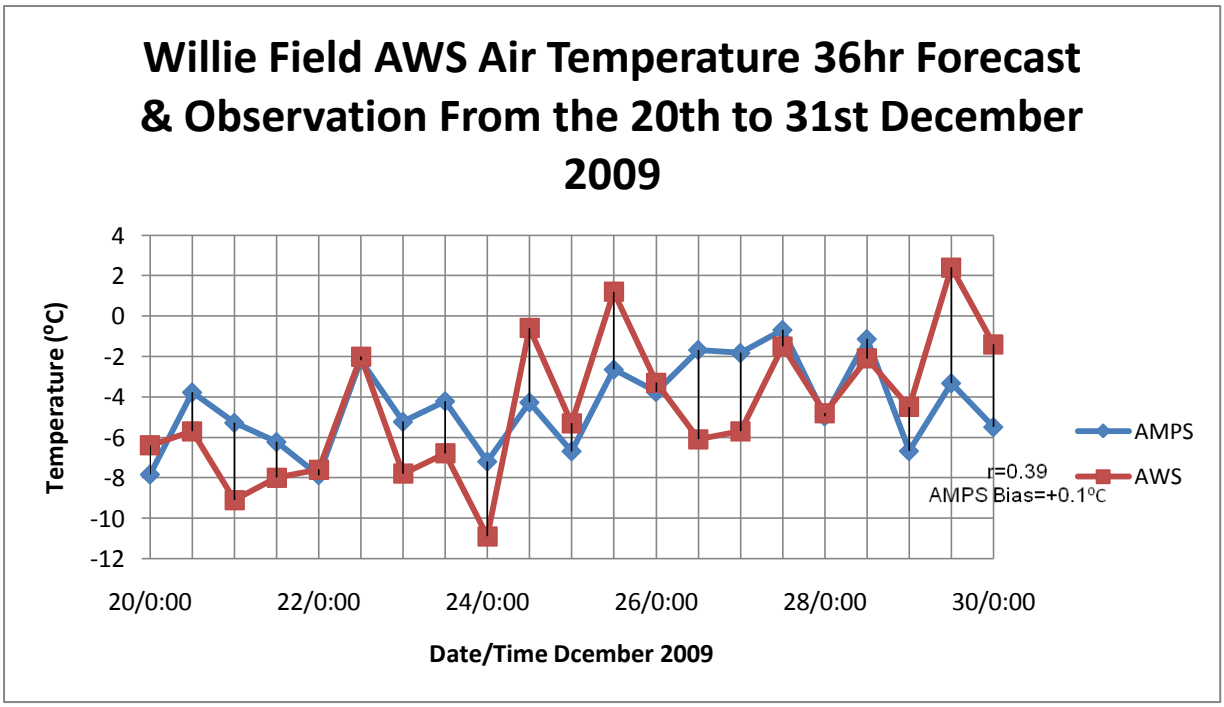


3Biv) Wind Direction

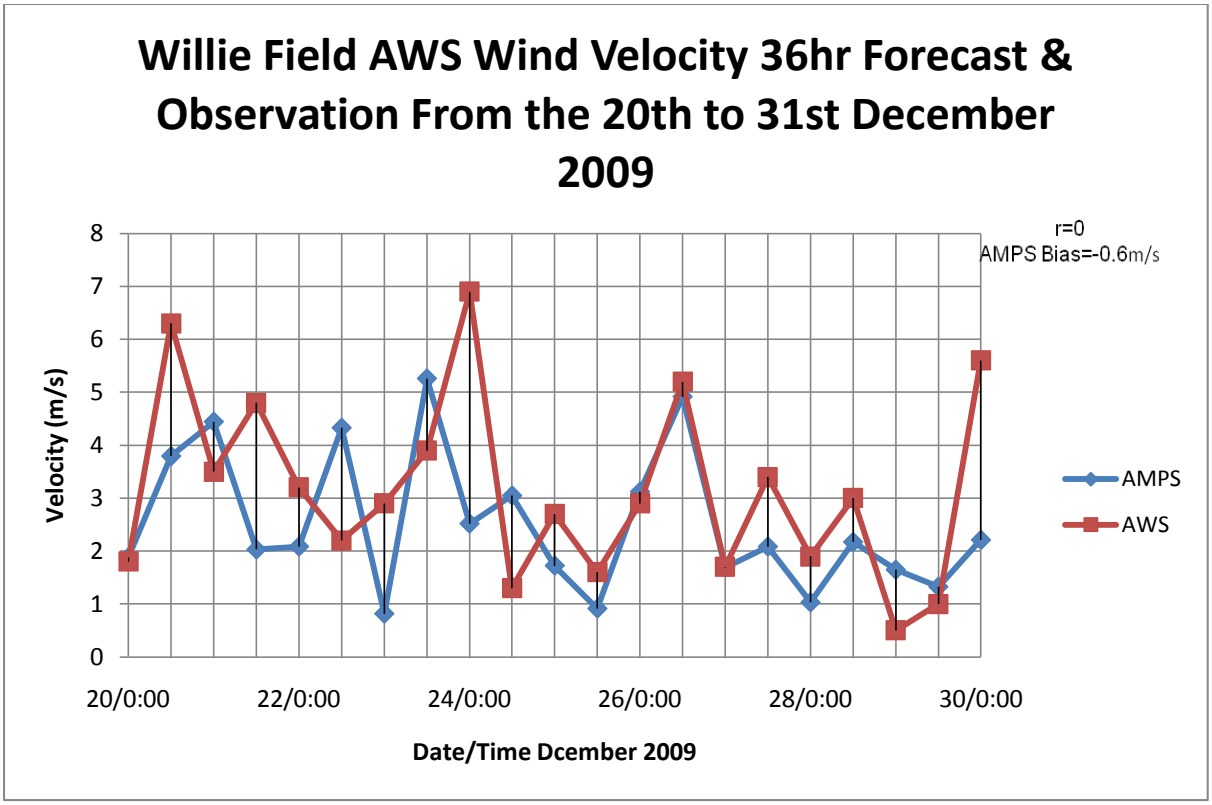
3C) AMPS 36 hour forecasts. Forecasted every 12 hours from 25th to 31st December 2009.



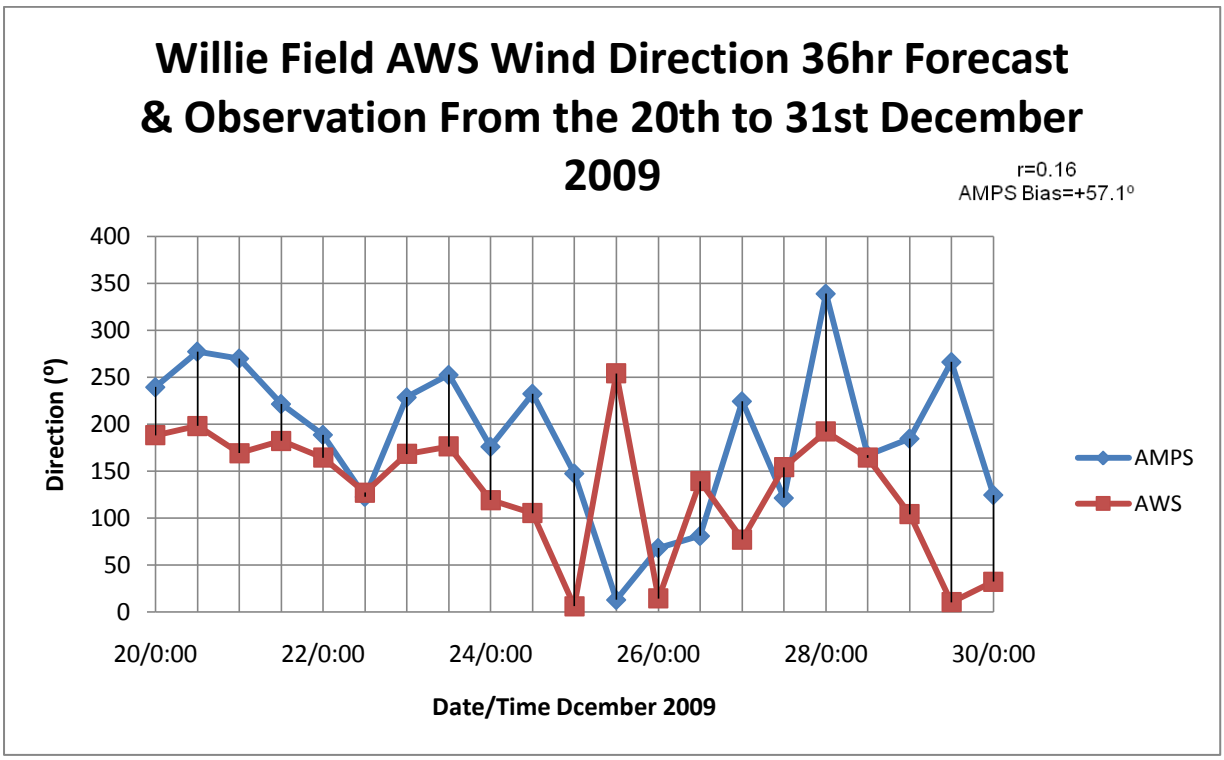
3Ci) Air Pressure



3Cii) Air Temperature



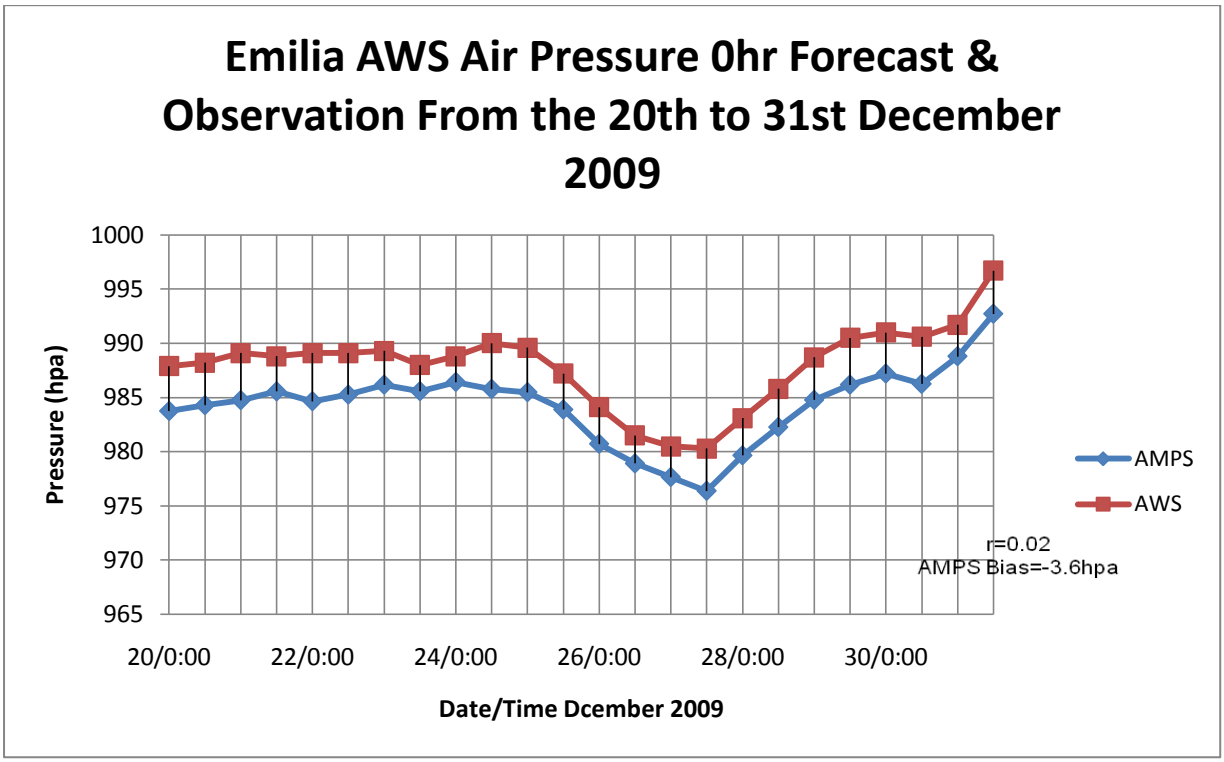
3Ciii**)** Wind Velocity



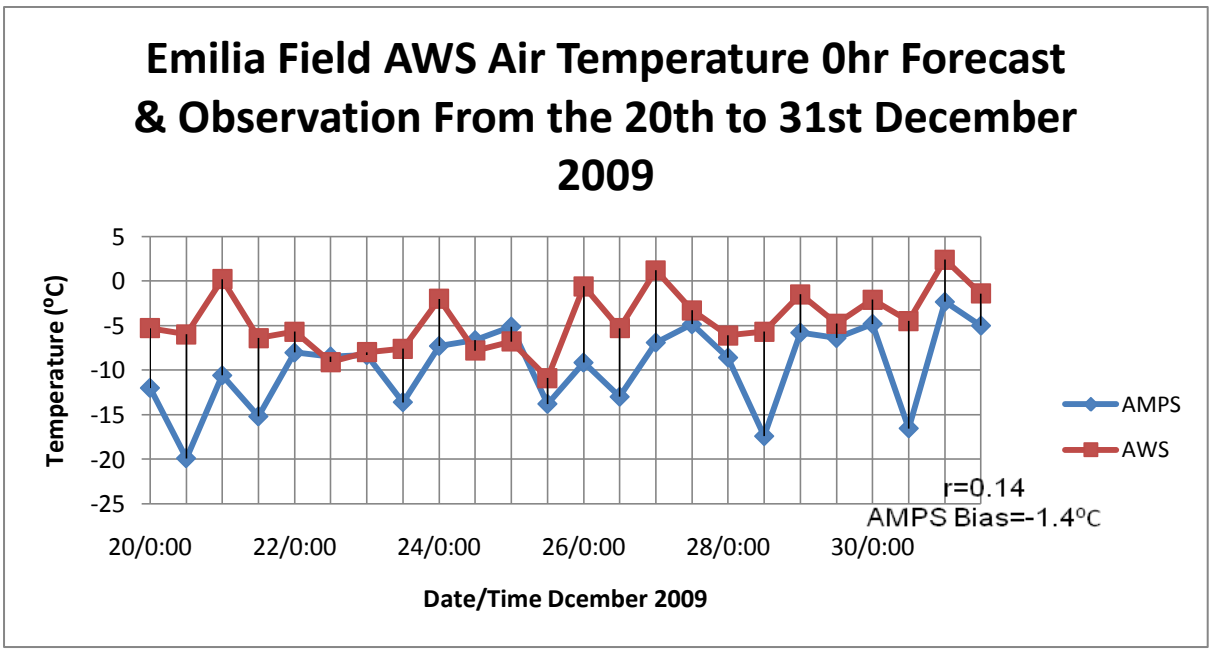
3Civ**)** Wind Direction

Appendix 4: Emilia AWS observations and corresponding forecasts.

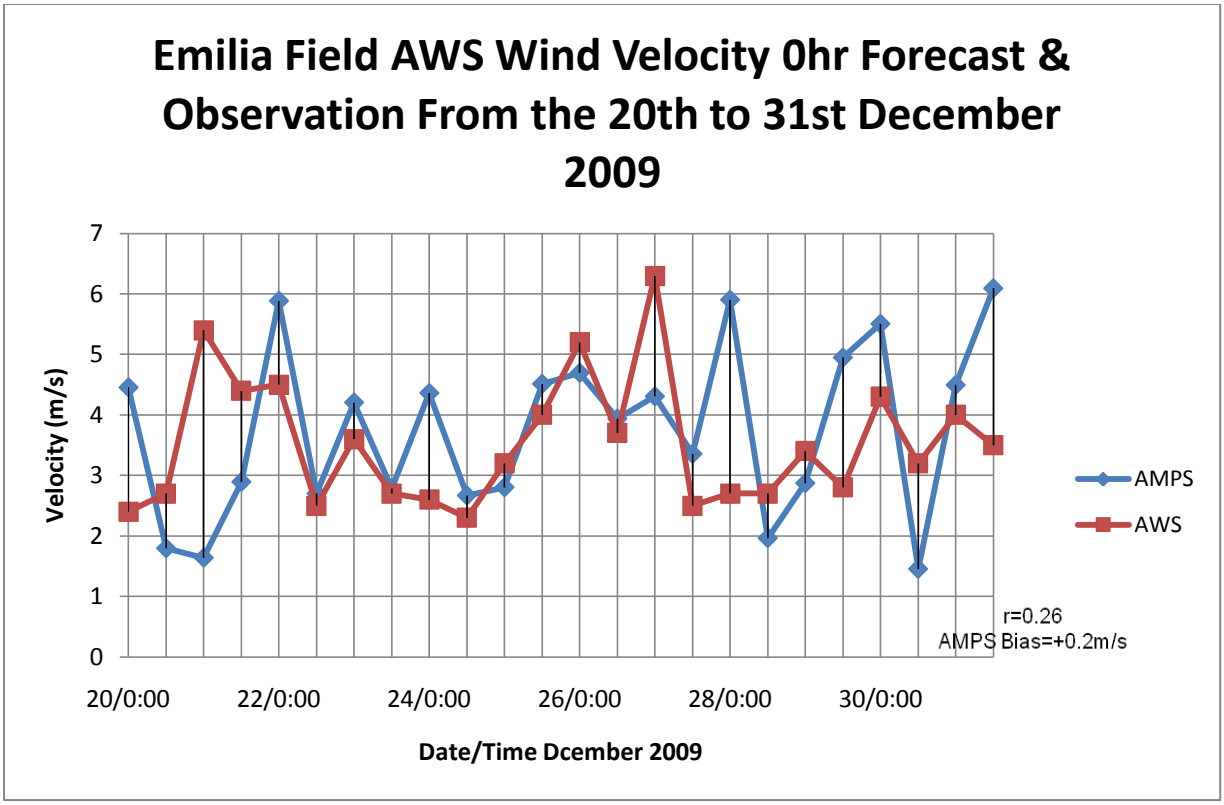
4A) AMPS 0 hour forecasts. Forecasted every 12 hours from 25th to 31st December 2009.



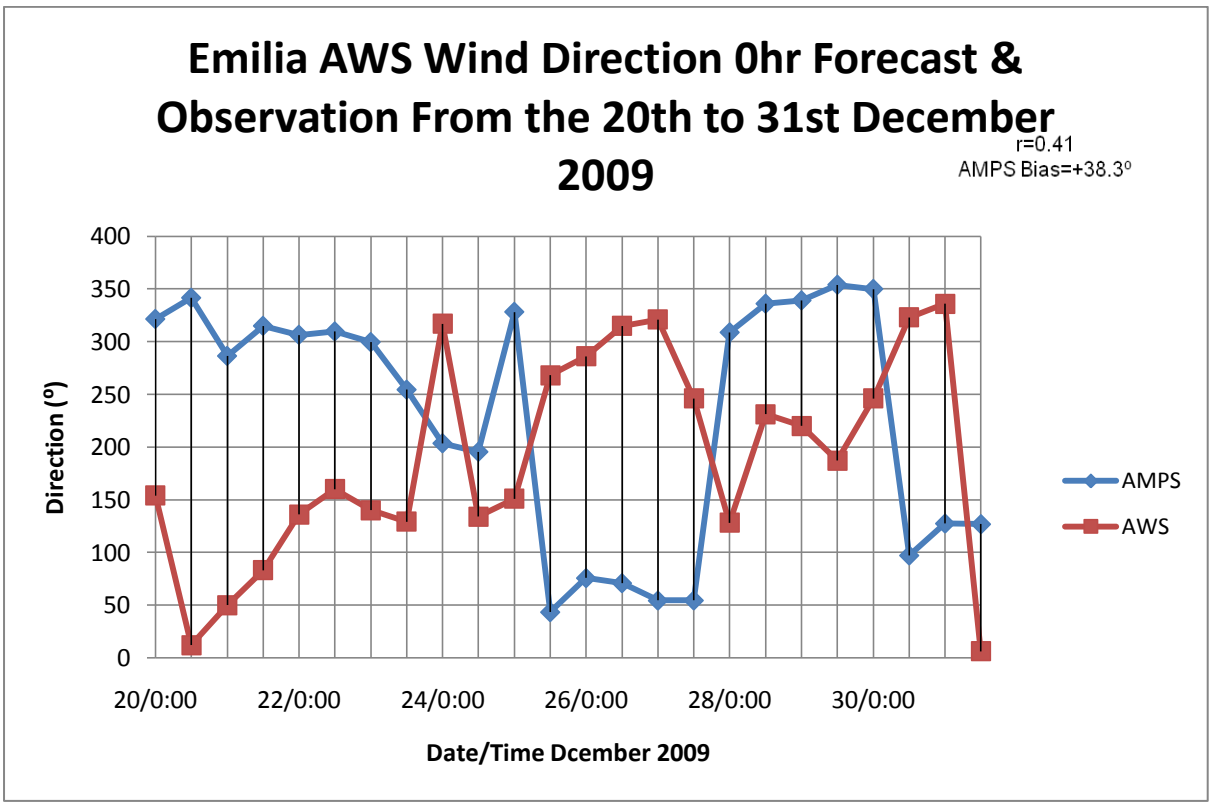
4Ai) Air Pressure



4Aii) Air Temperature

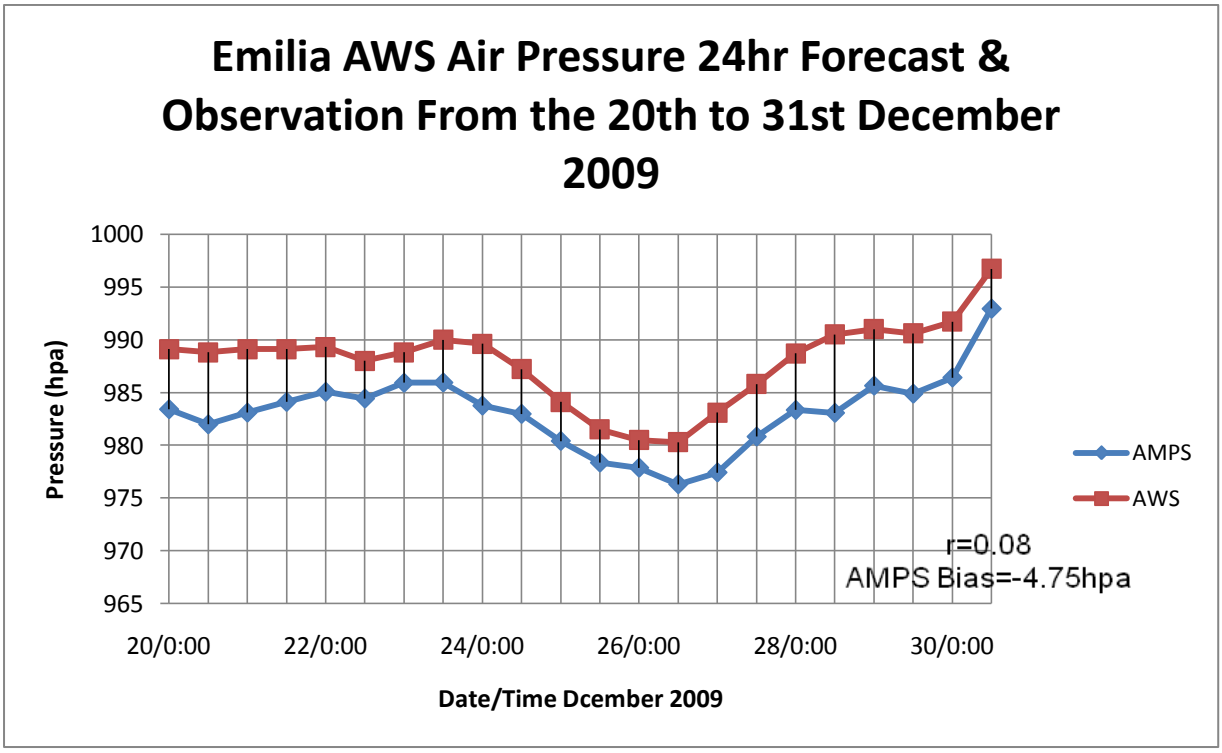


4Aiii**)** Wind Velocity

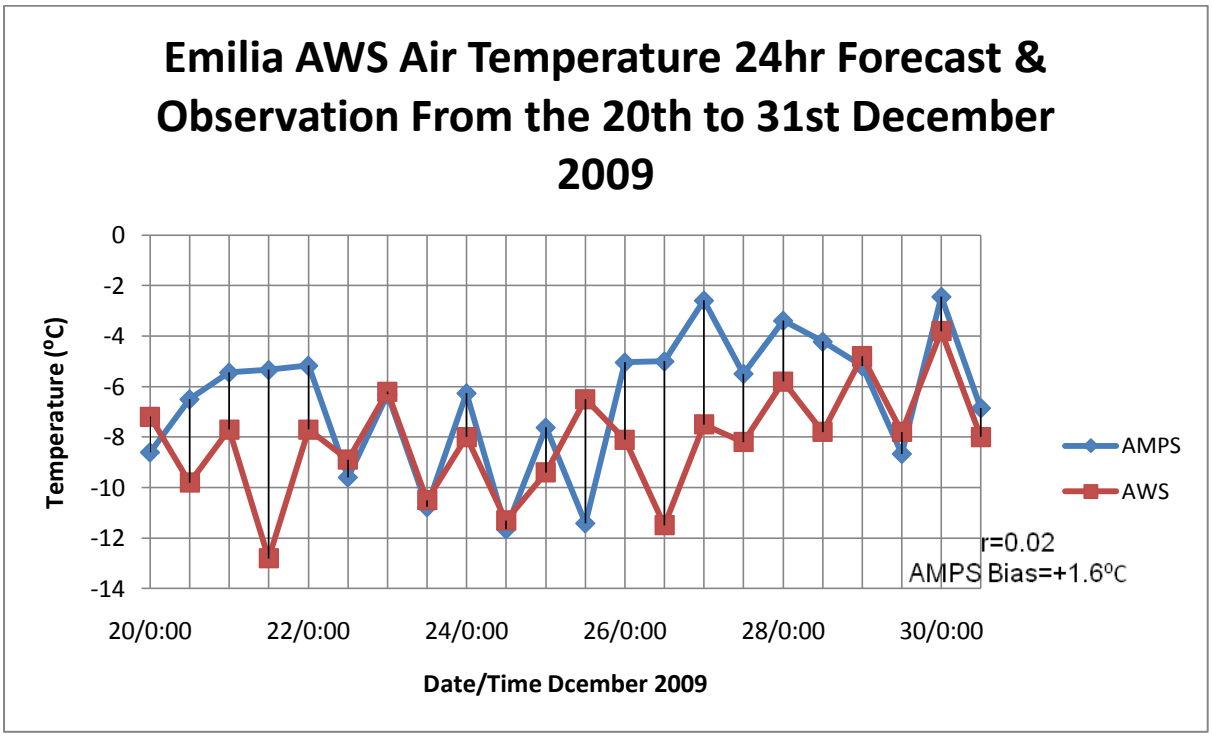


4Aiv**)** Wind Direction

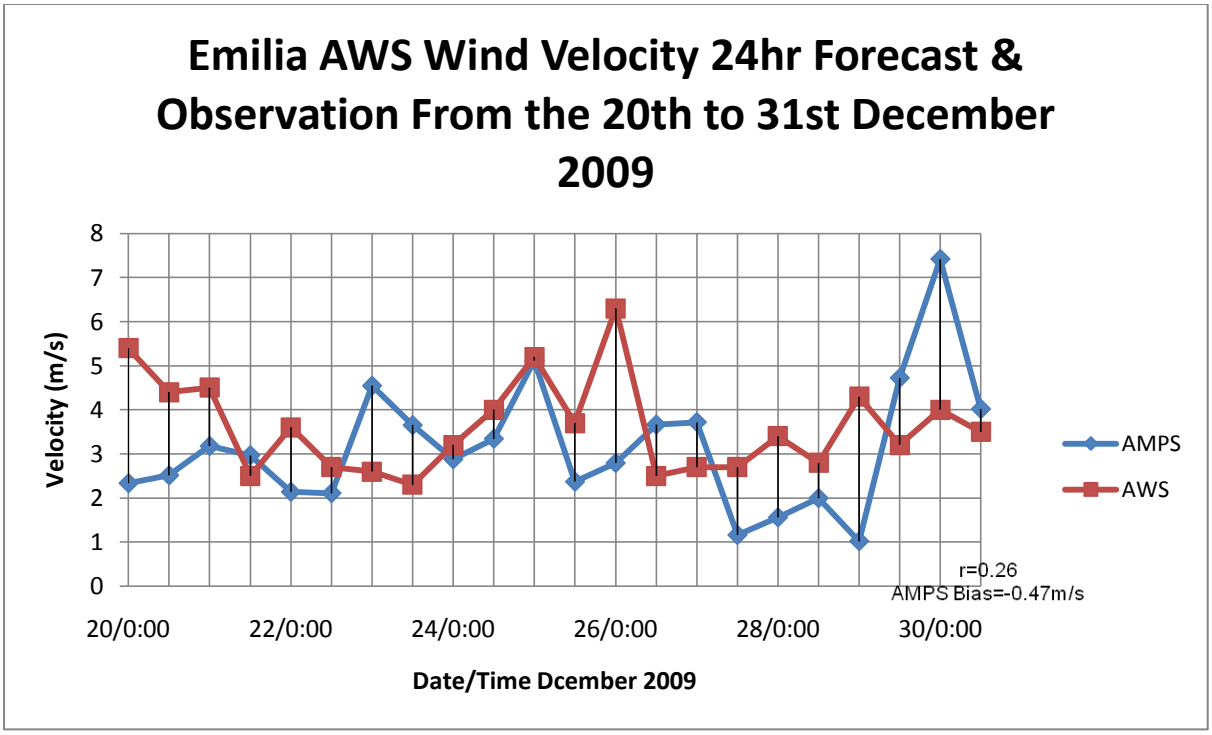
4B) AMPS 24 hour forecasts. Forecasted every 12 hours from 25th to 31st December 2009.



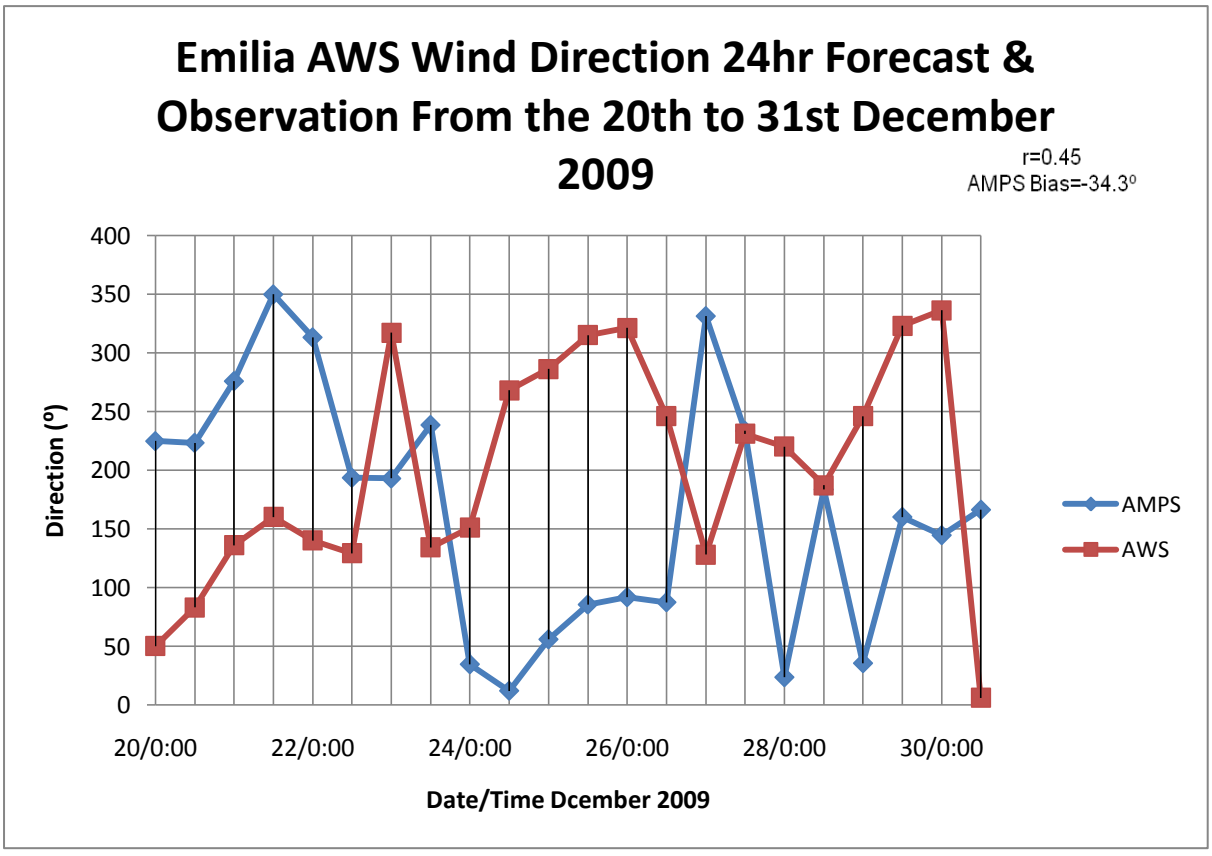
4Bi) Air Pressure



4Bii) Air Temperature

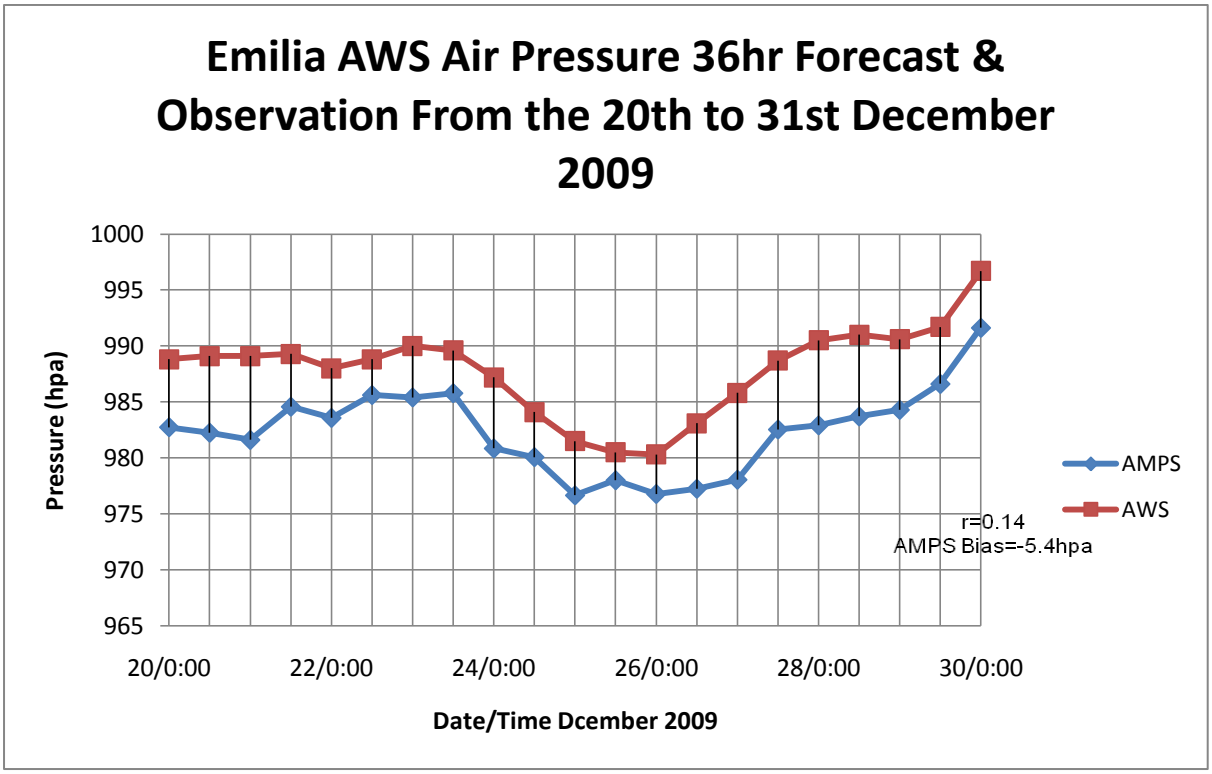


4Biii) Wind Velocity

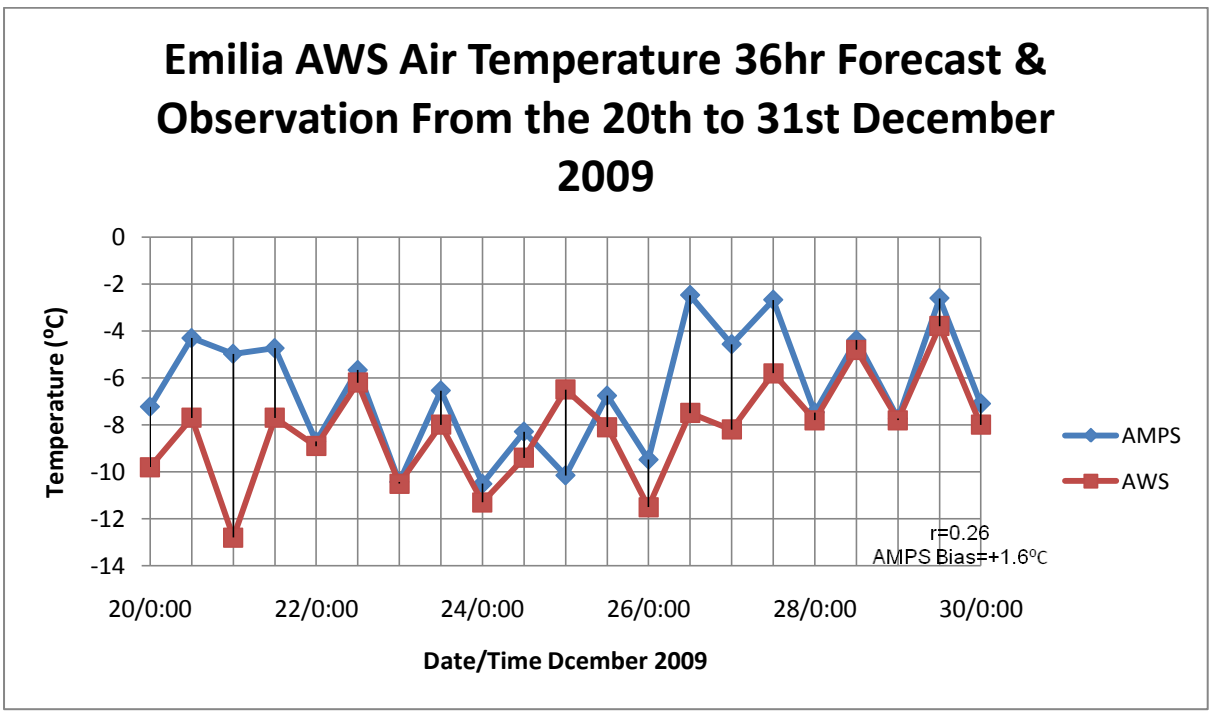


4Biv) Wind Direction

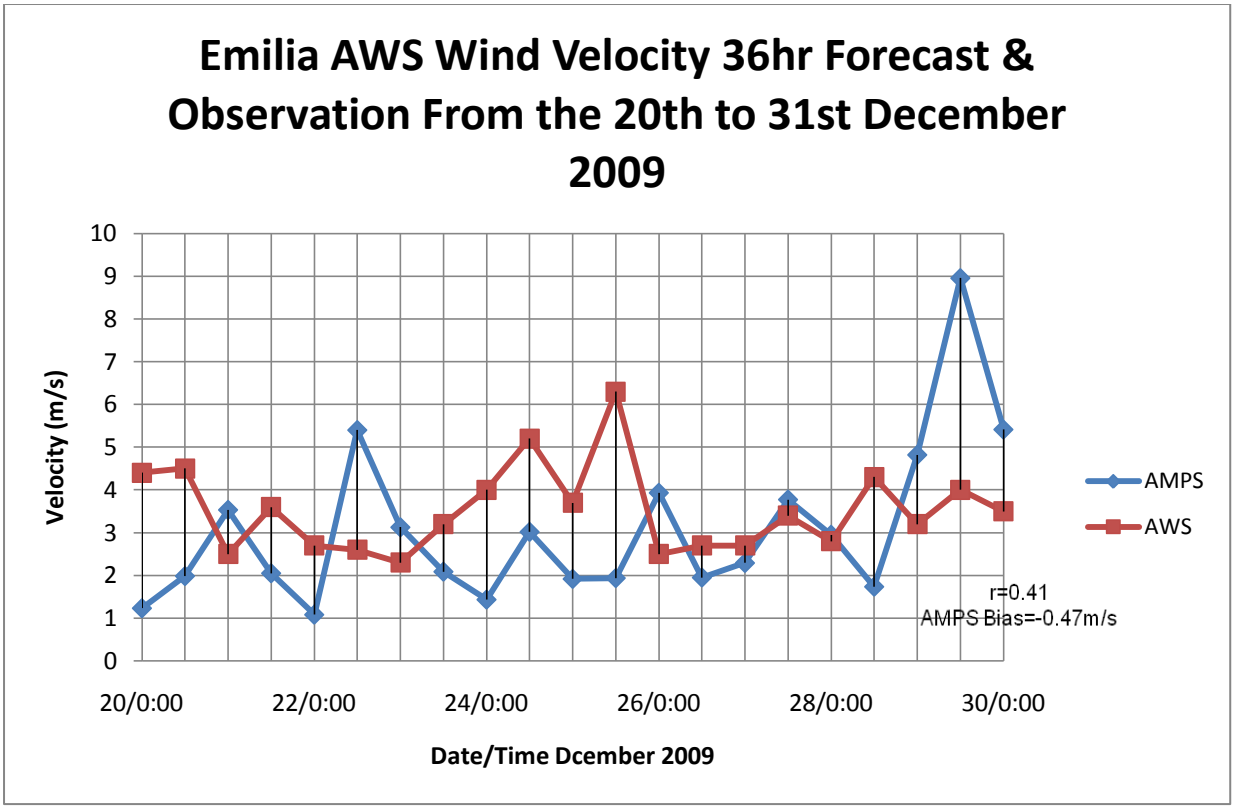
4C) AMPS 36 hour forecasts. Forecasted every 12 hours from 25th to 31st December 2009.



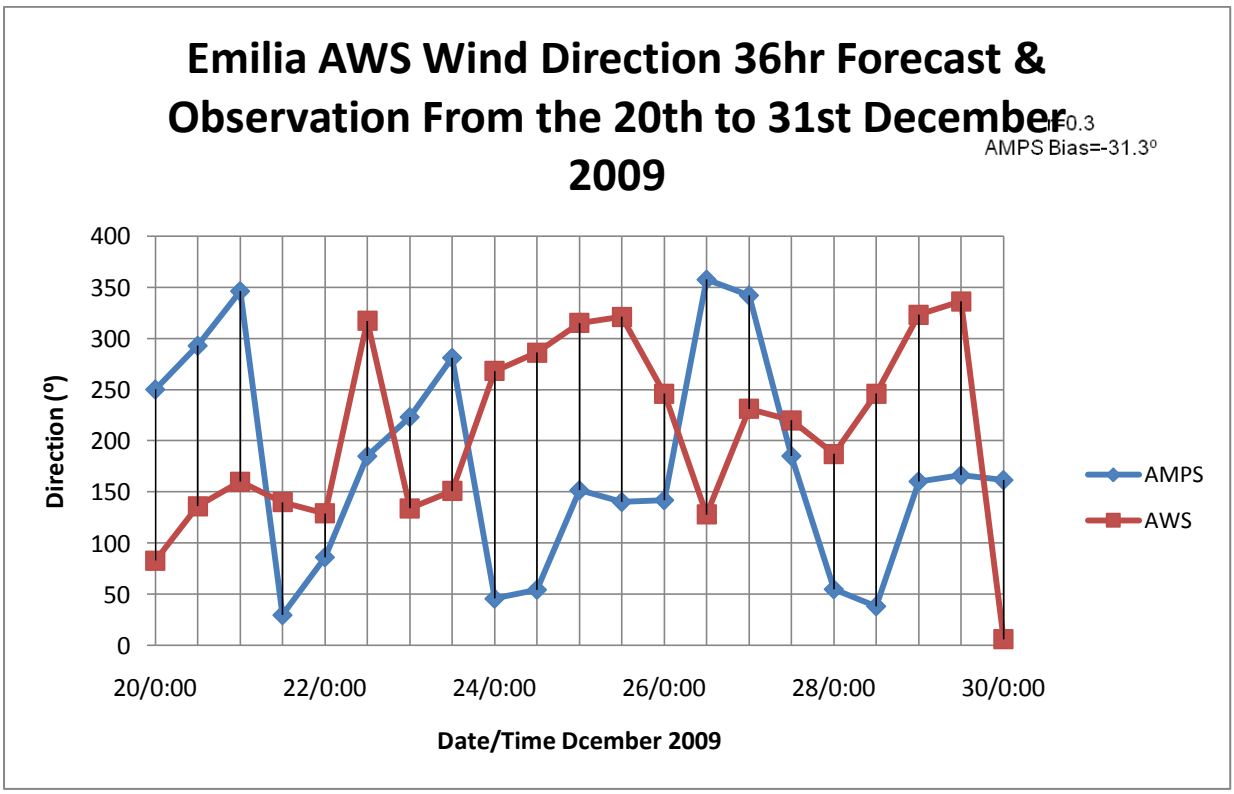
4Ci) Air Pressure



4Cii) Air Temperature



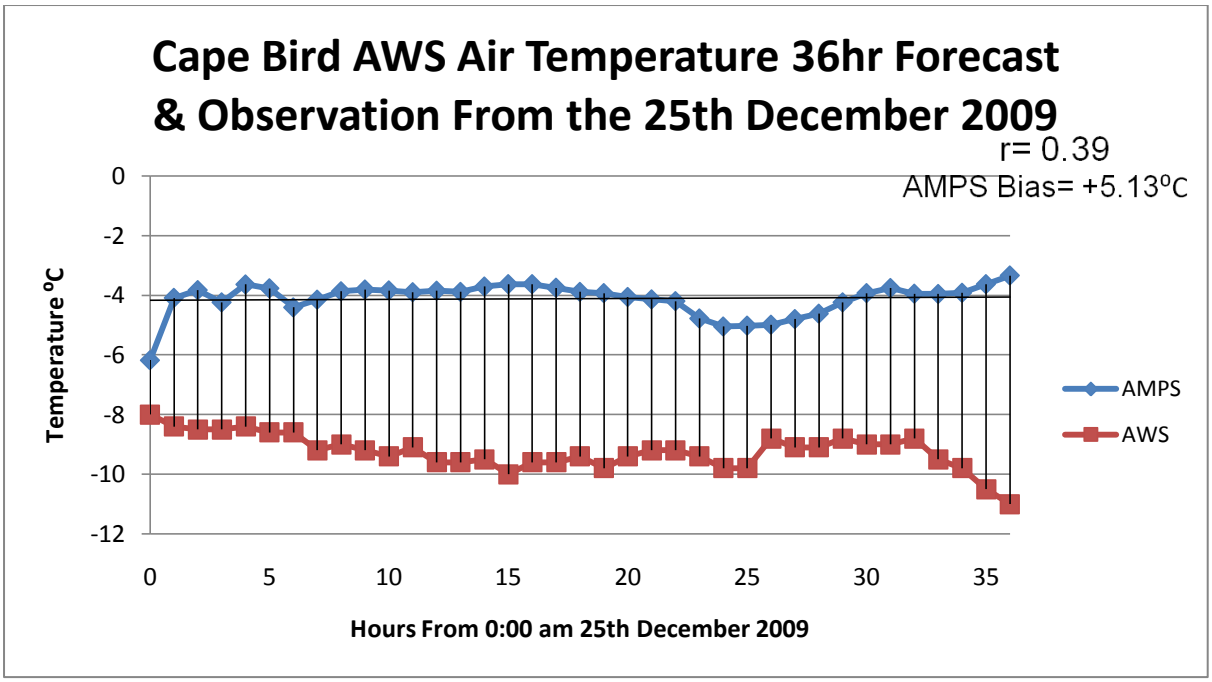
4Ciii) Wind Velocity



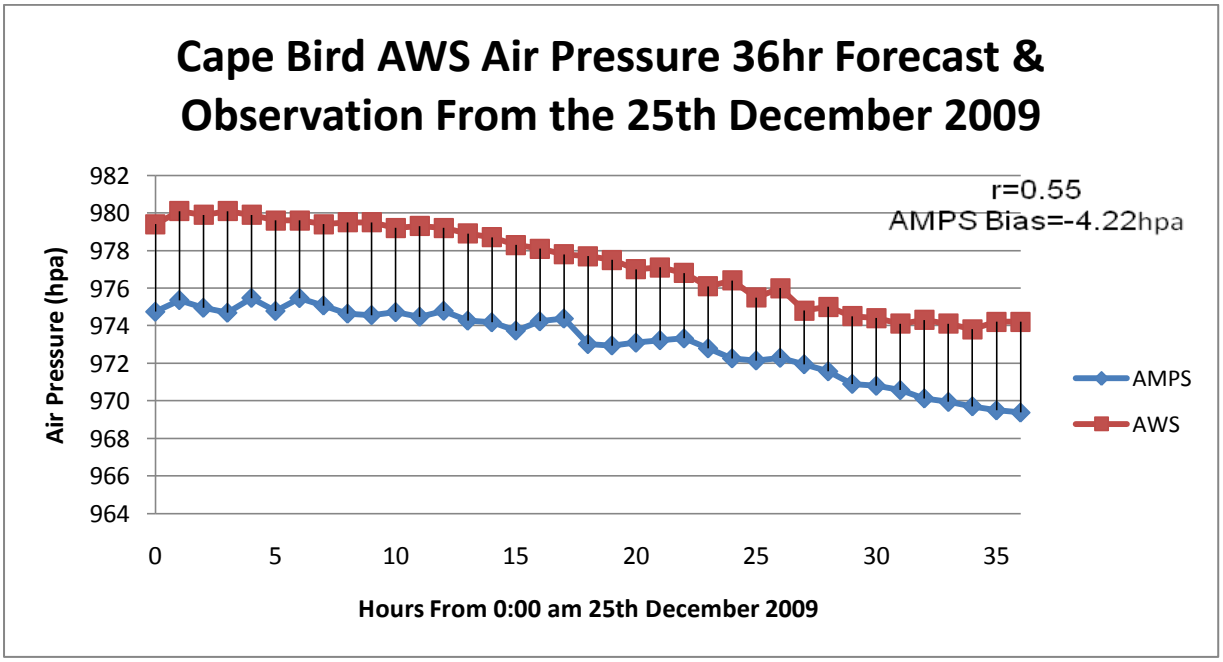
4Civ) Wind Direction

Appendix 5: Case Study: Christmas Day Forecast and Observation. AMPS Forecast Issued 0:00am 25th December 2009 which is correlated with hourly observations over a 36 hour period until 12pm 26th December 2009.

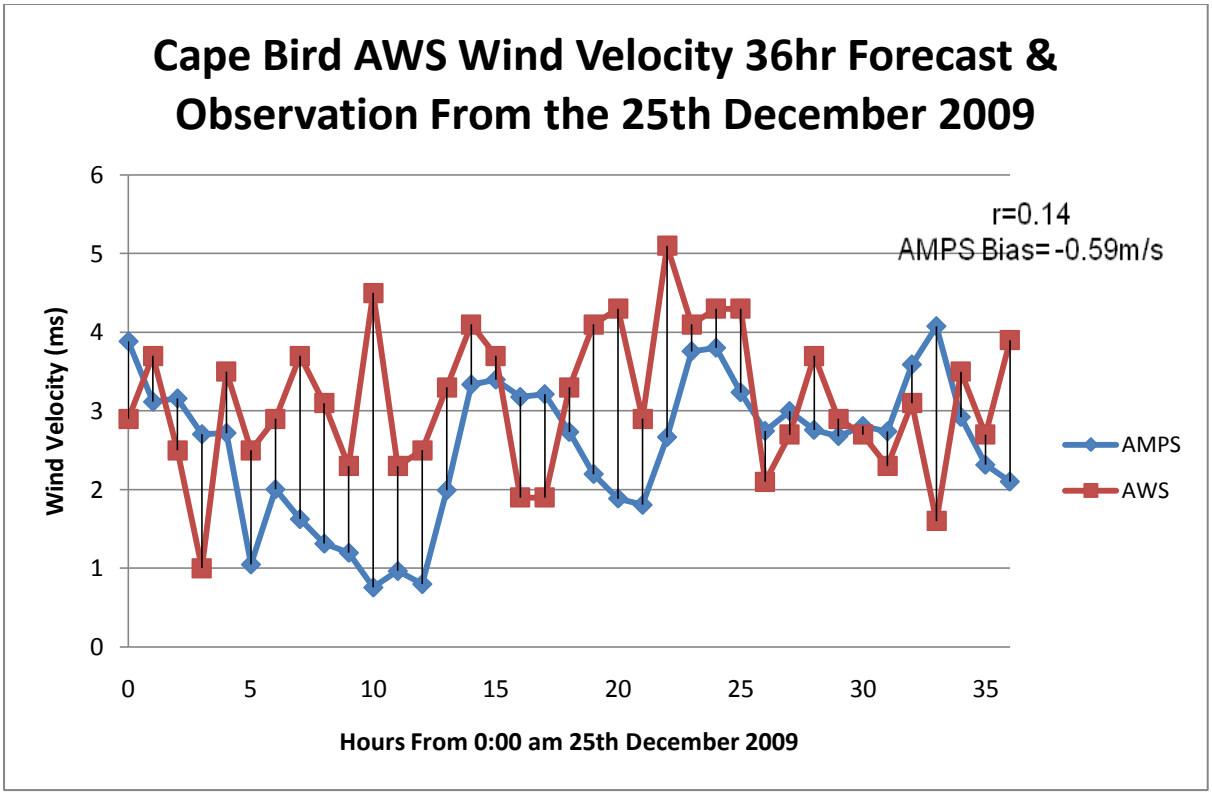
5A) Cape Bird AWS observations correlated with 0:00am 25th December 2009 AMPS forecast.



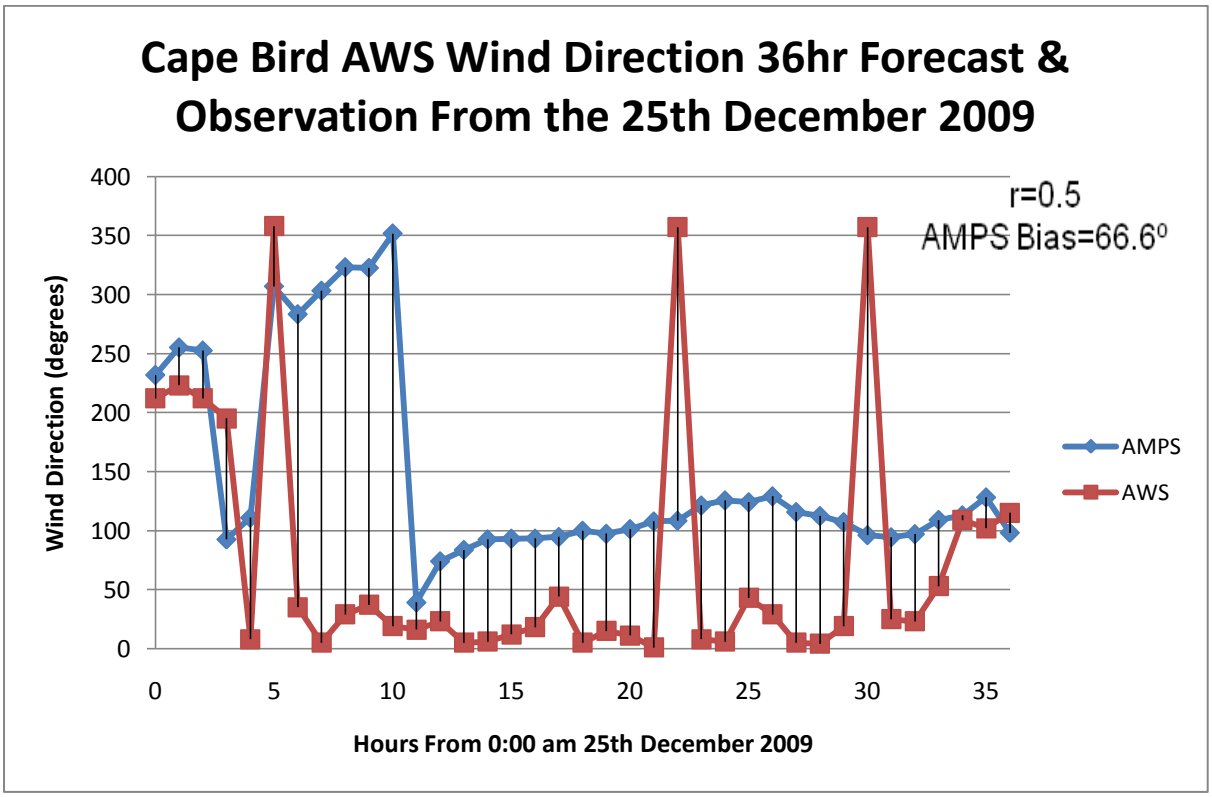
5Ai) Air Temperature



5Aii) Air Pressure

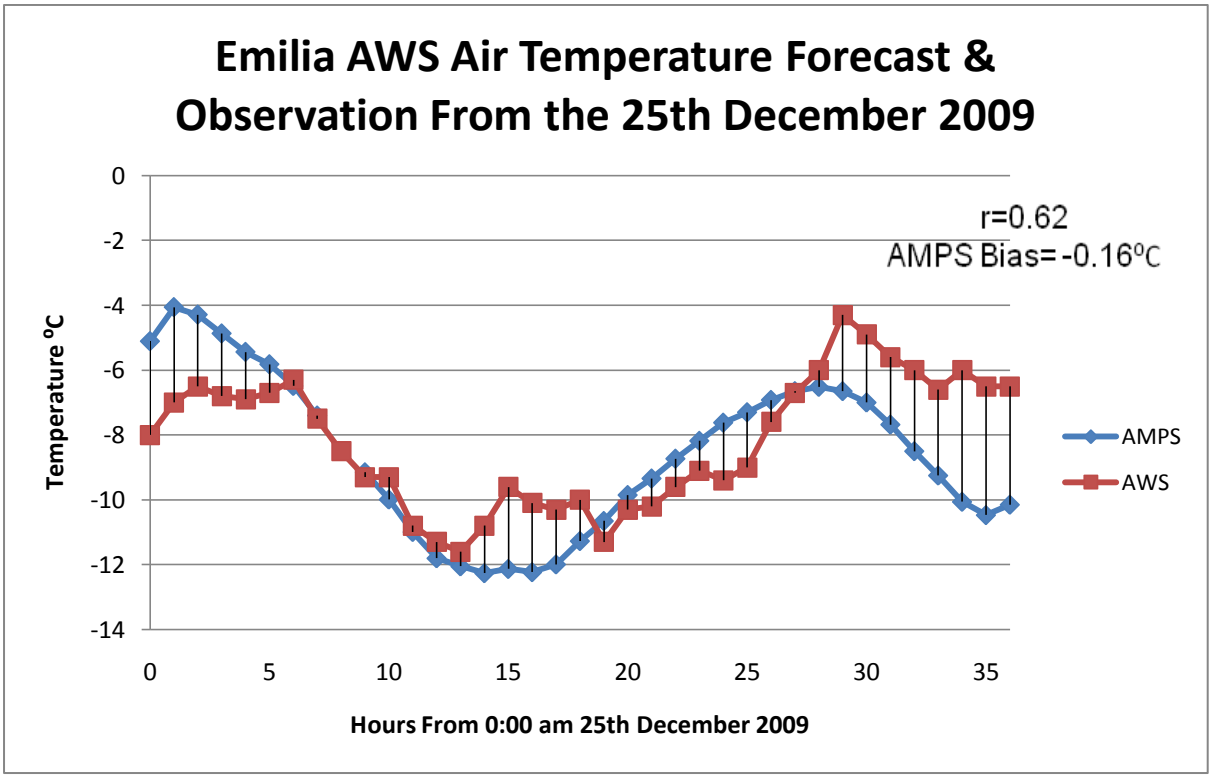


5Aiii) Wind Velocity

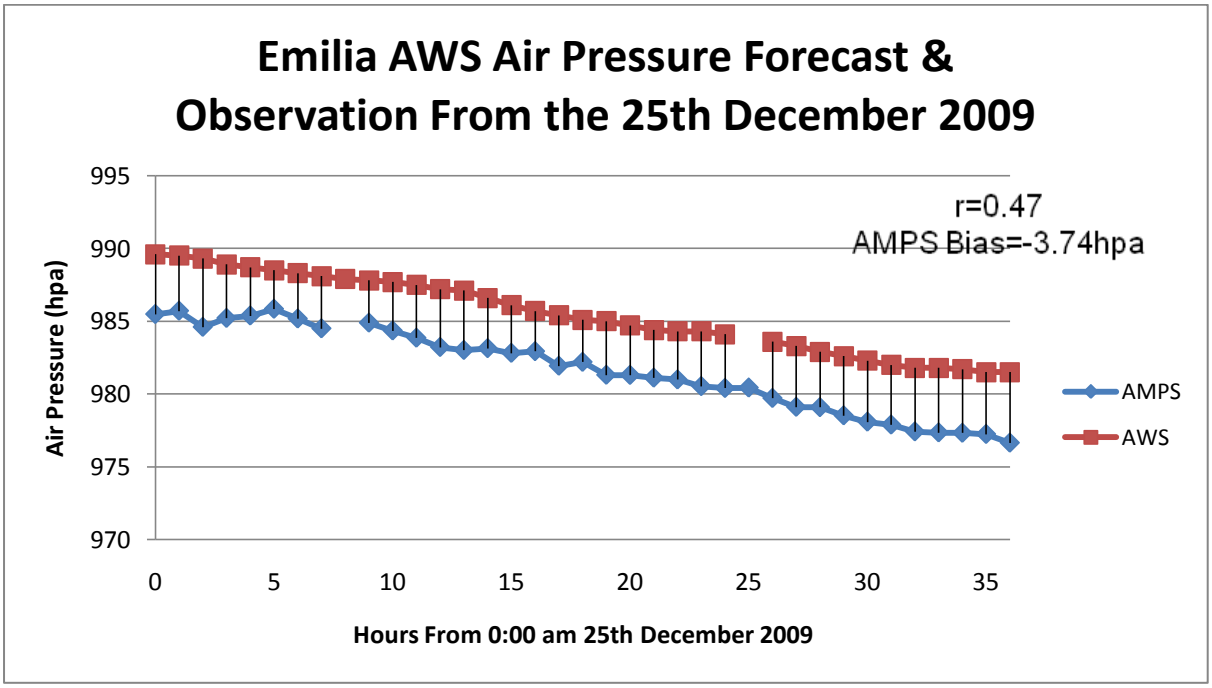


5Aiv) Wind Direction

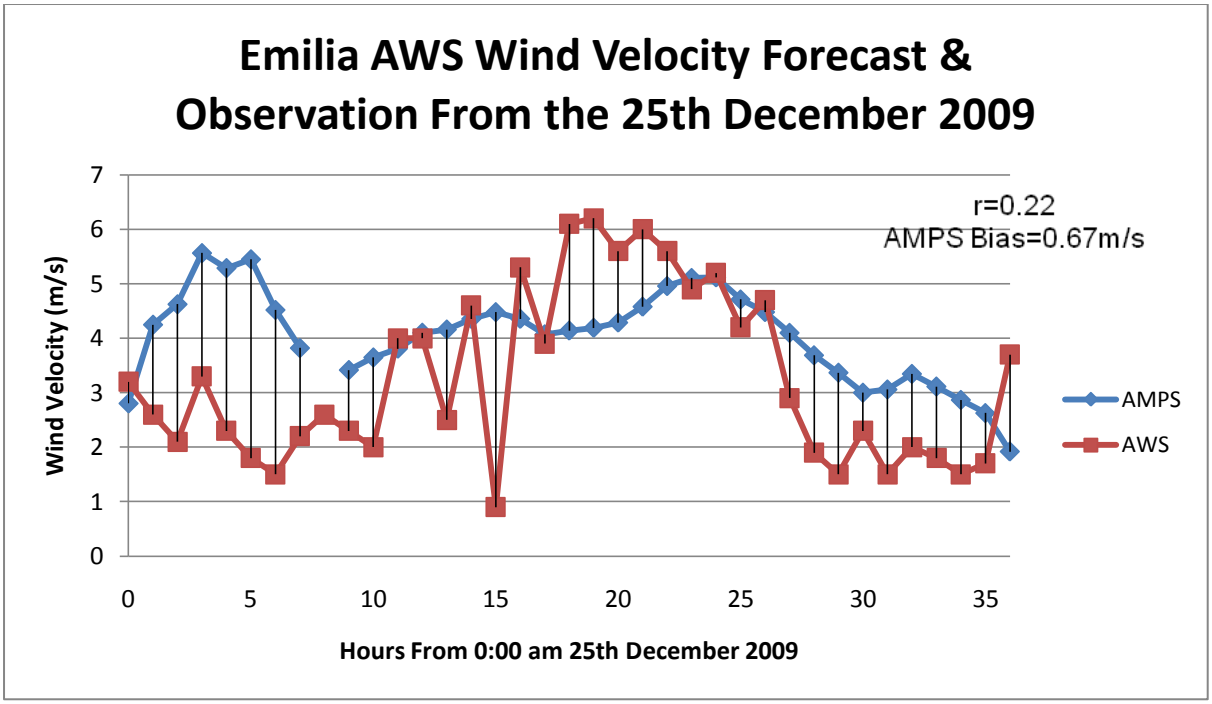
5B) Emilia AWS observations correlated with 0:00am 25th December 2009 AMPS forecast.



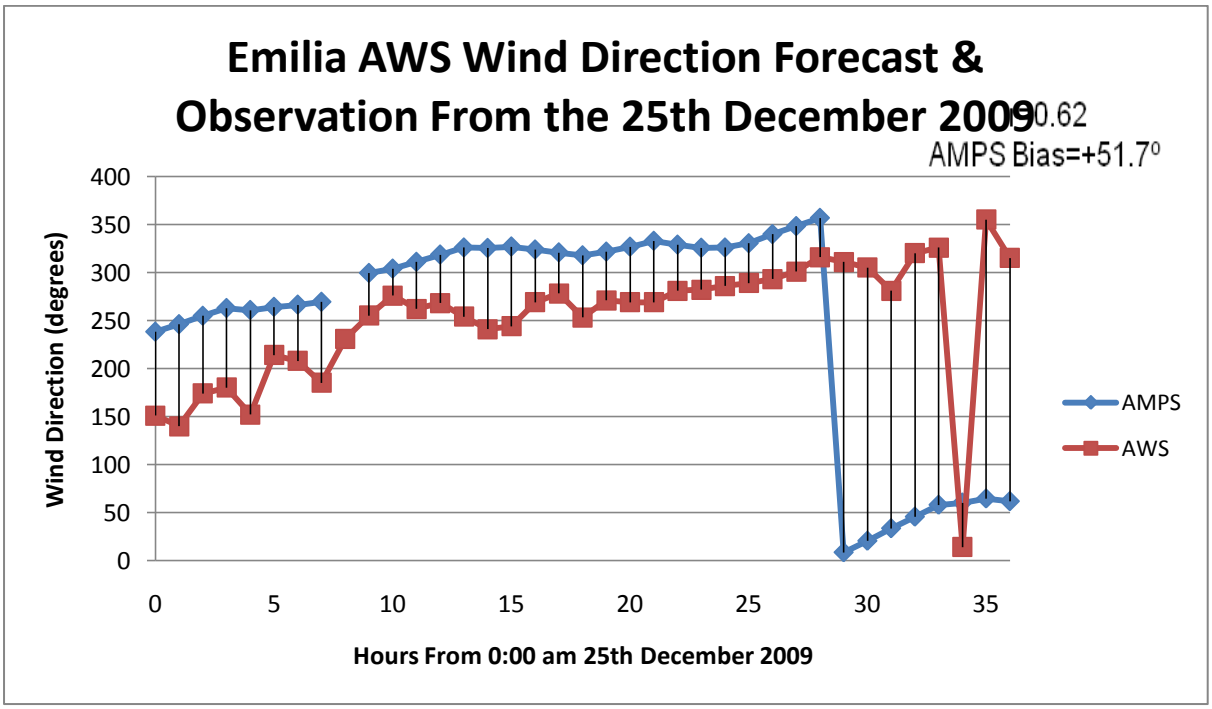
5Bi) Air Temperature



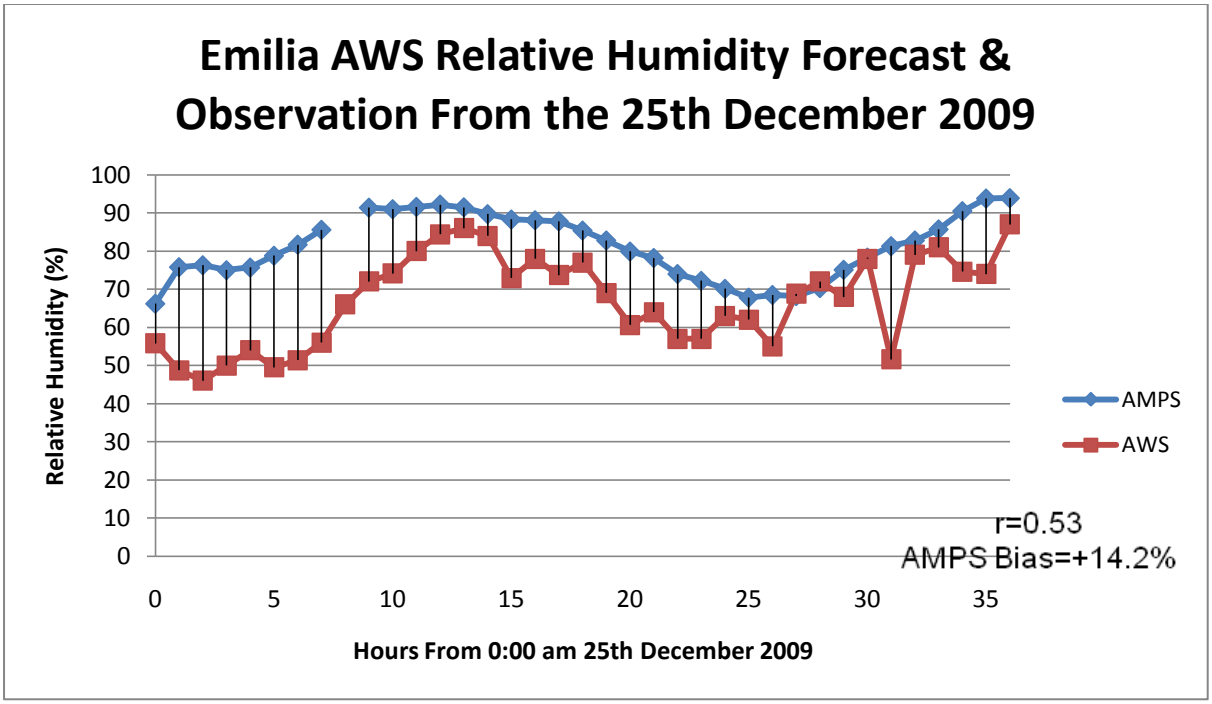
5Bii) Air Pressure



5Biii) Wind Velocity

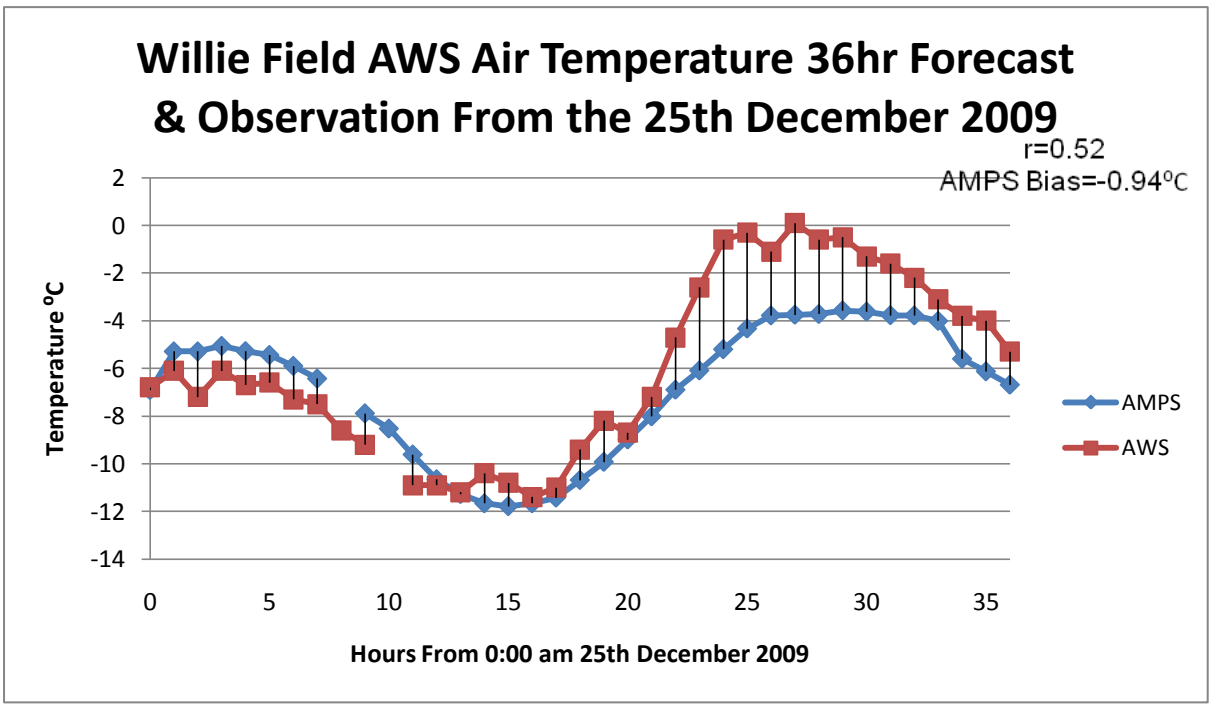


5Biv) Wind Direction

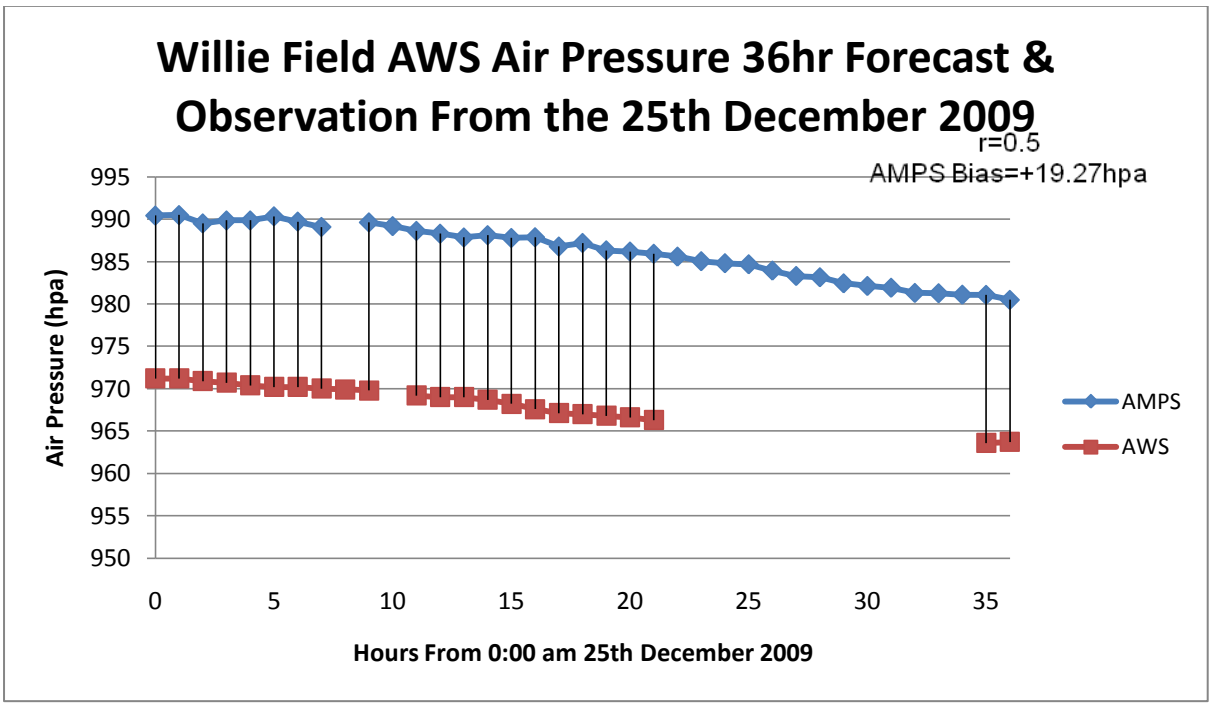


5Bv) Relative Humidity

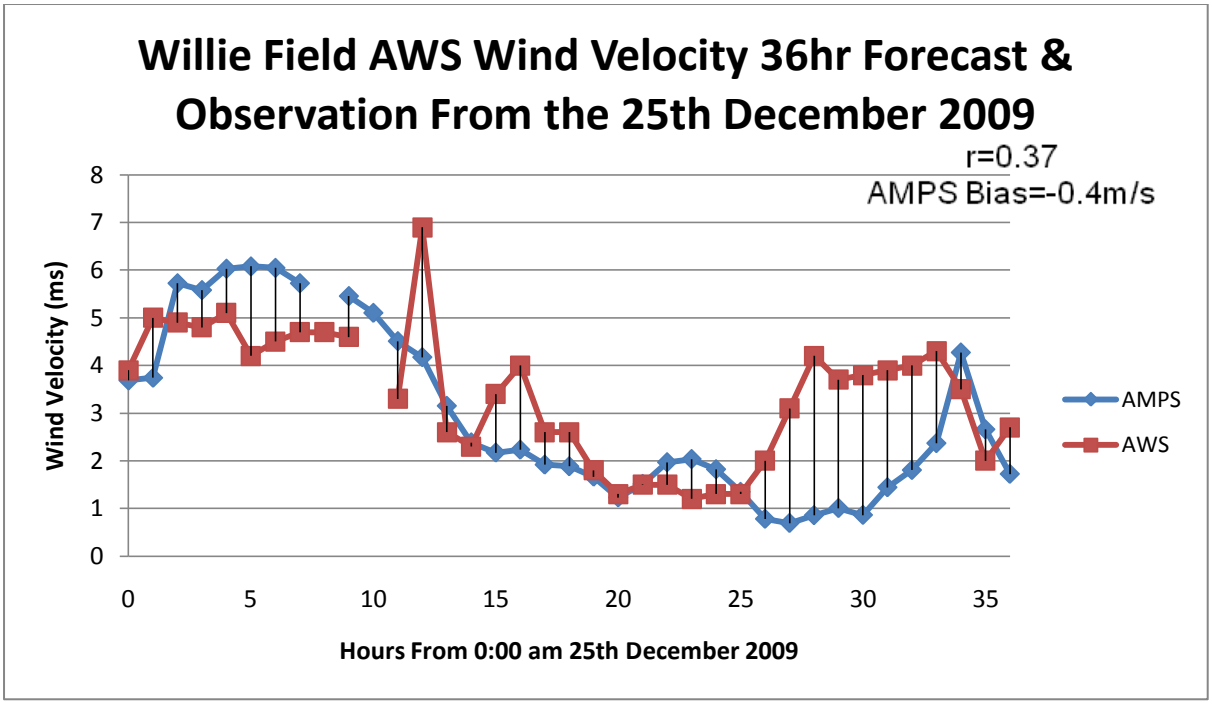
5C) Willie Field AWS observations correlated with 0:00am 25th December 2009 AMPS forecast.



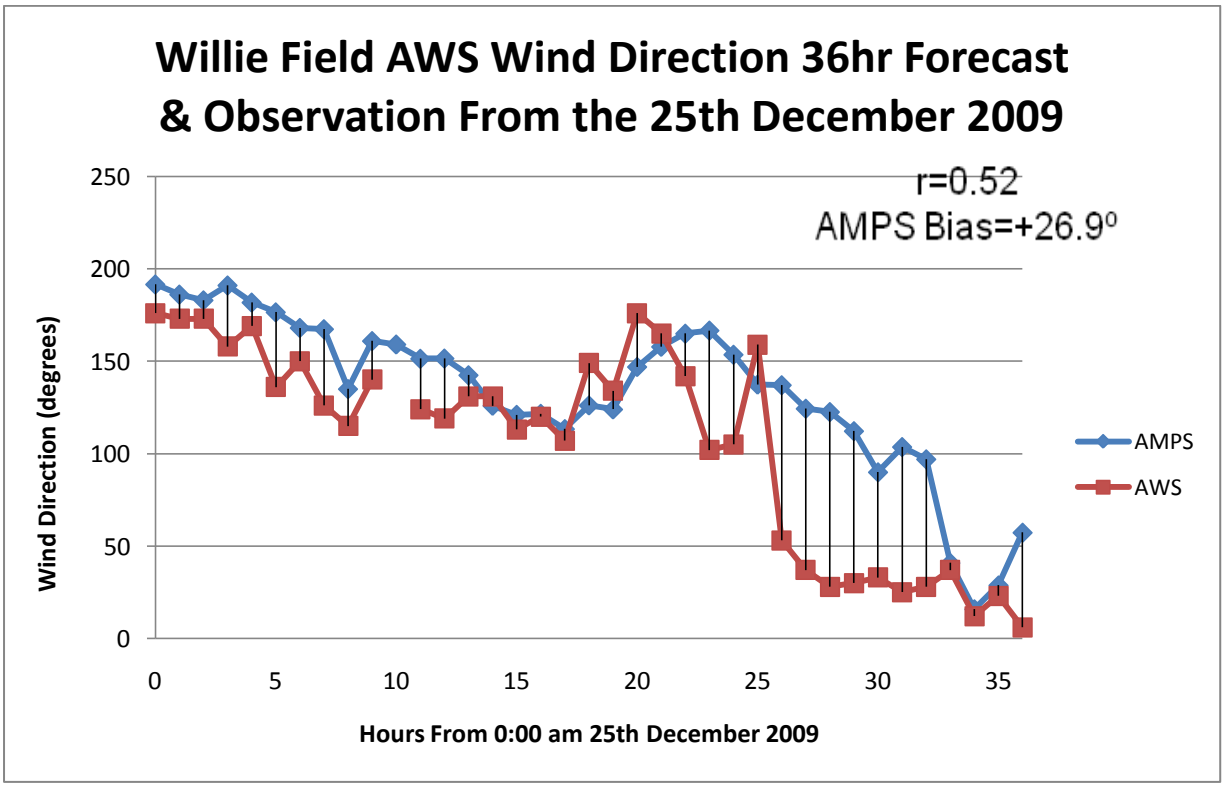
5Ci) Air Temperature



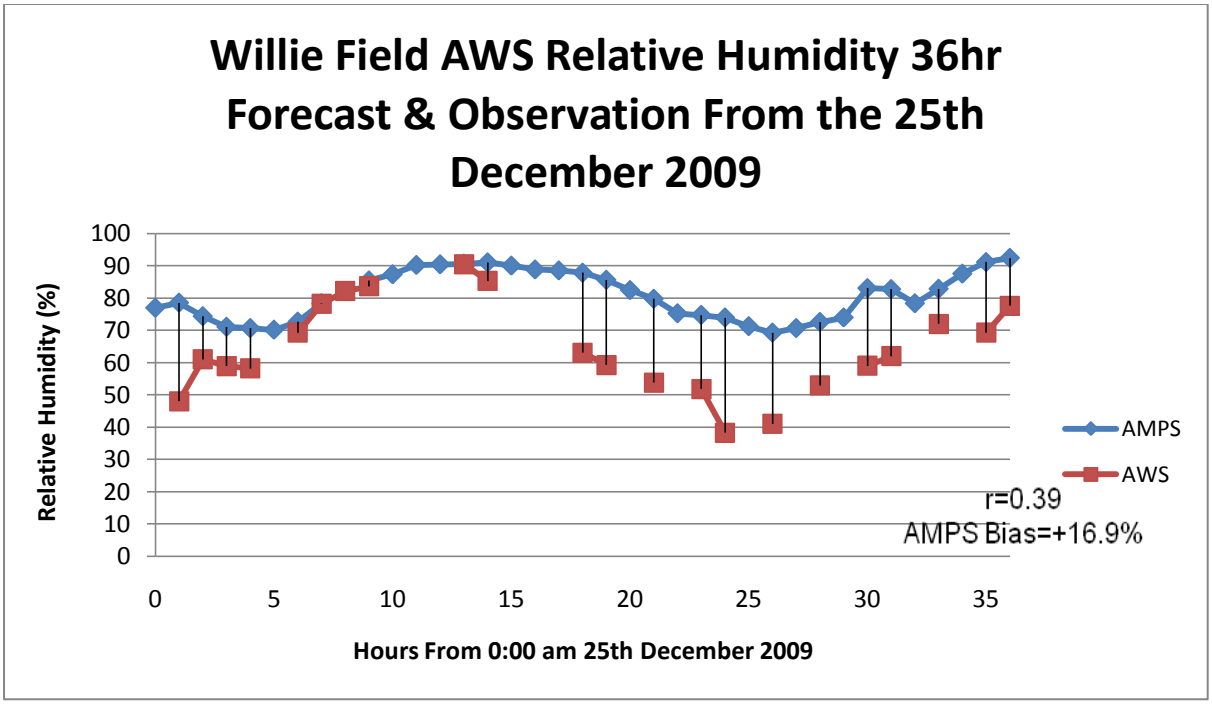
5Cii) Air Pressure



5Ciii**)** Wind Velocity

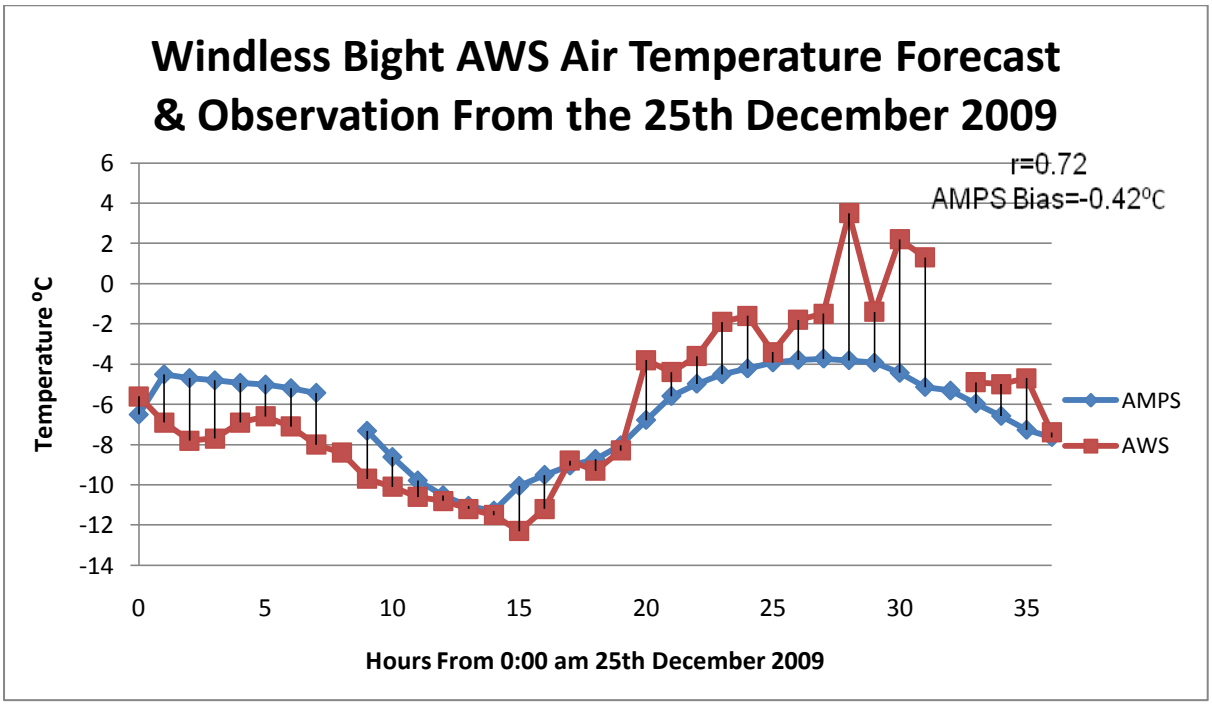


5Civ**)** Wind Direction

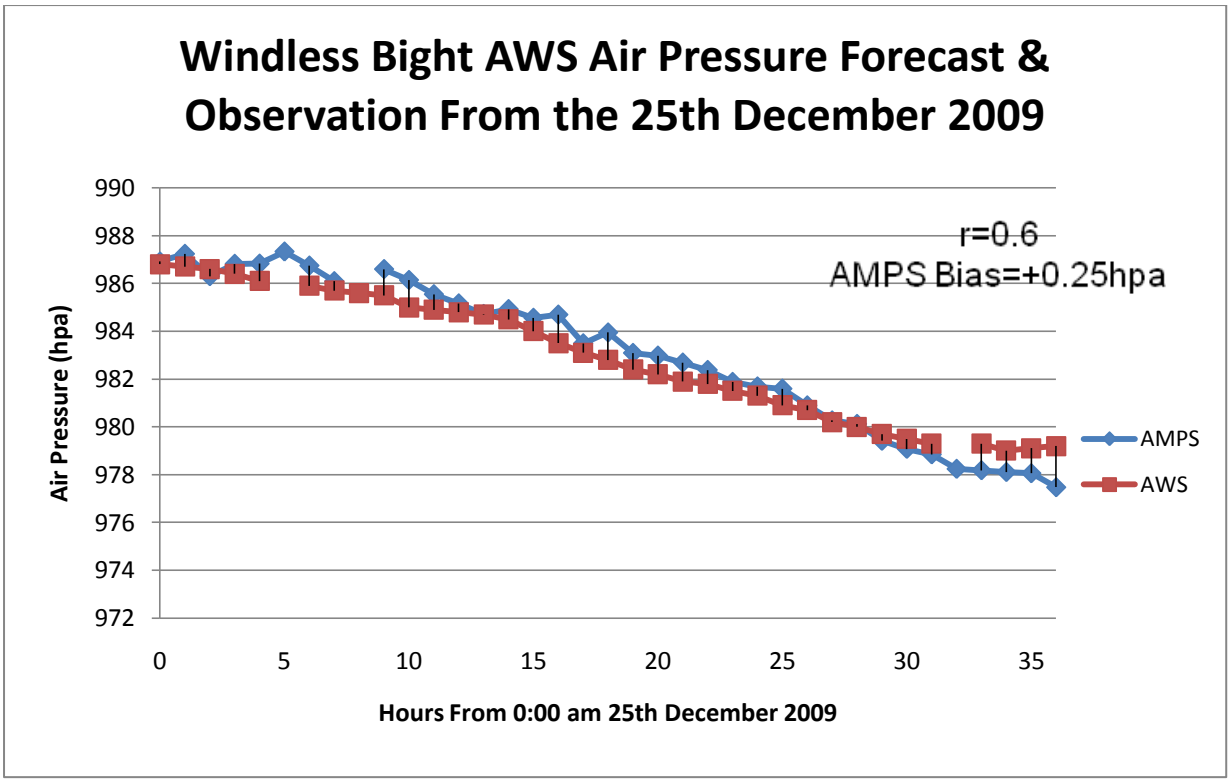


5Cv) Relative Humidity

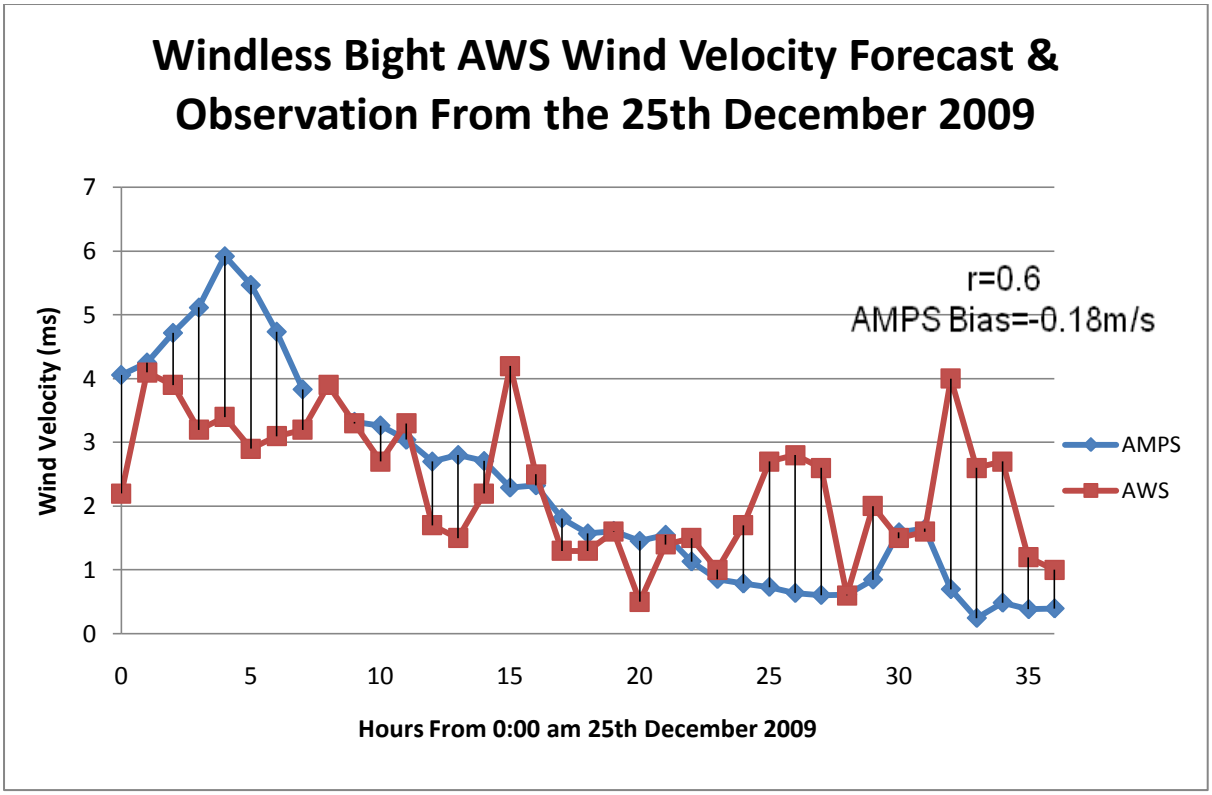
5D) Windless Bight AWS observations correlated with 0:00am 25th December 2009 AMPS forecast.



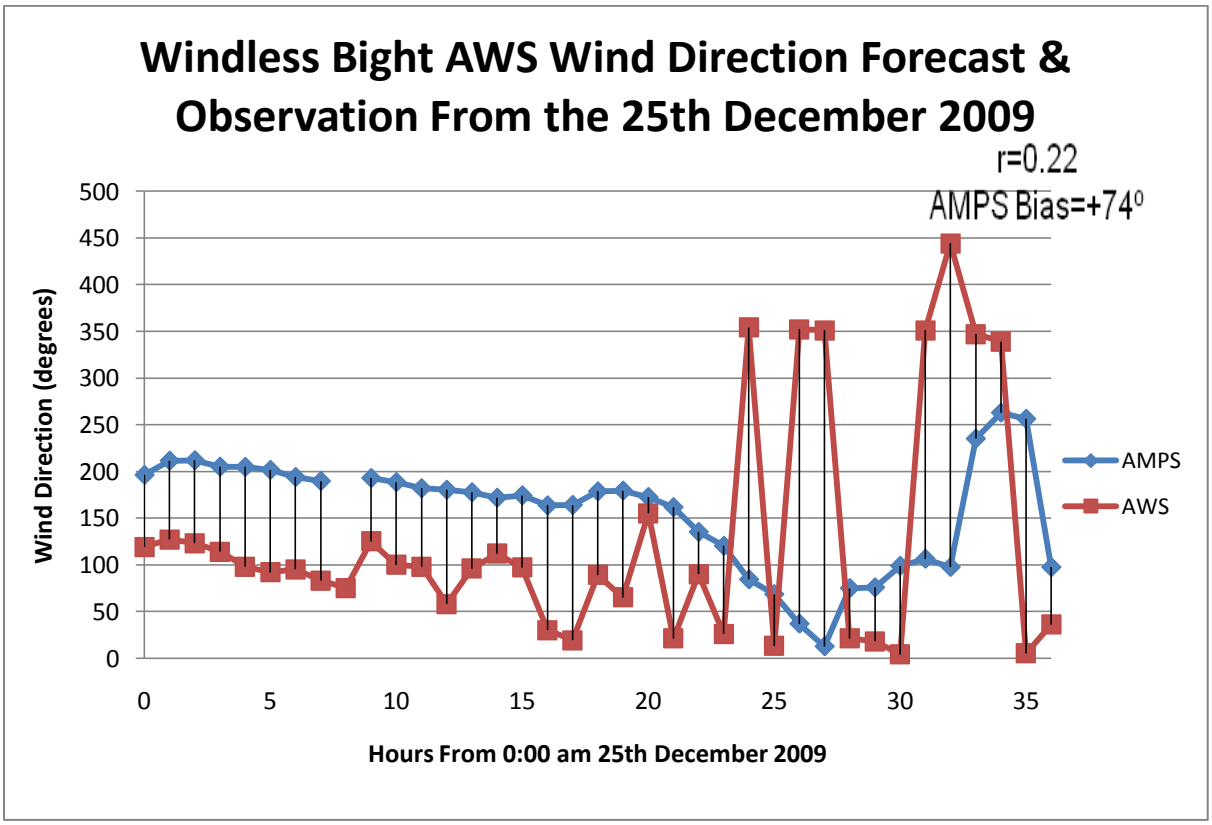
5Di) Air Temperature



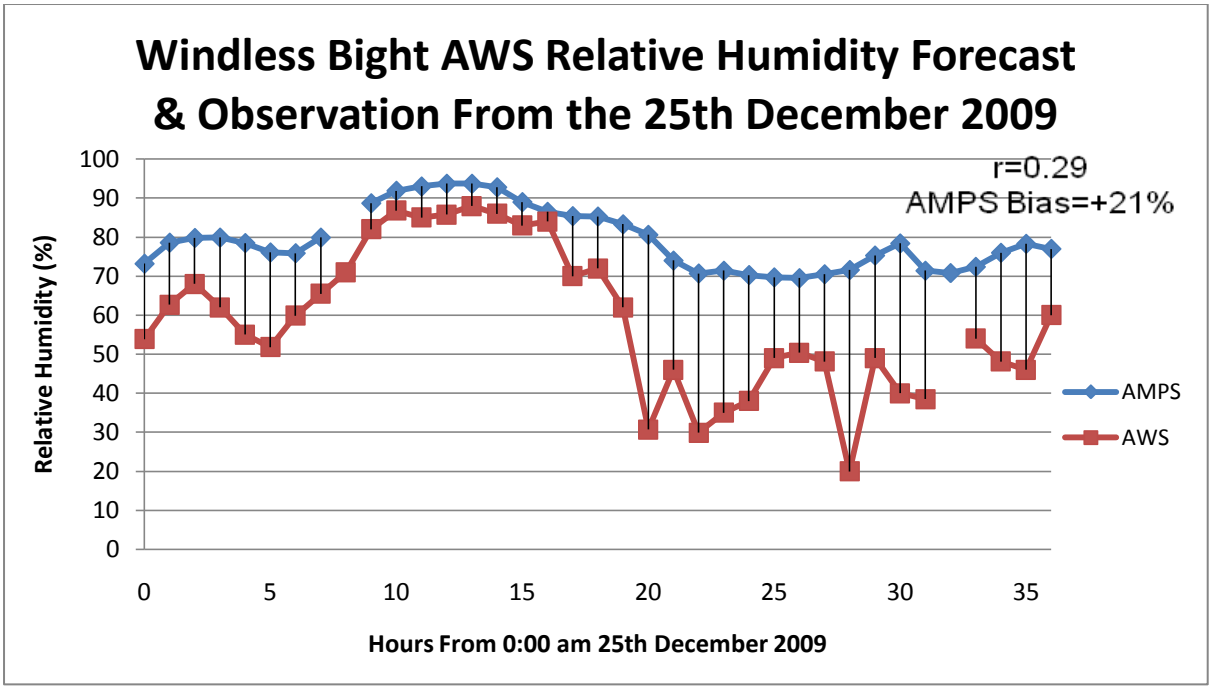
5Dii) Air Pressure



5Diii) Wind Velocity

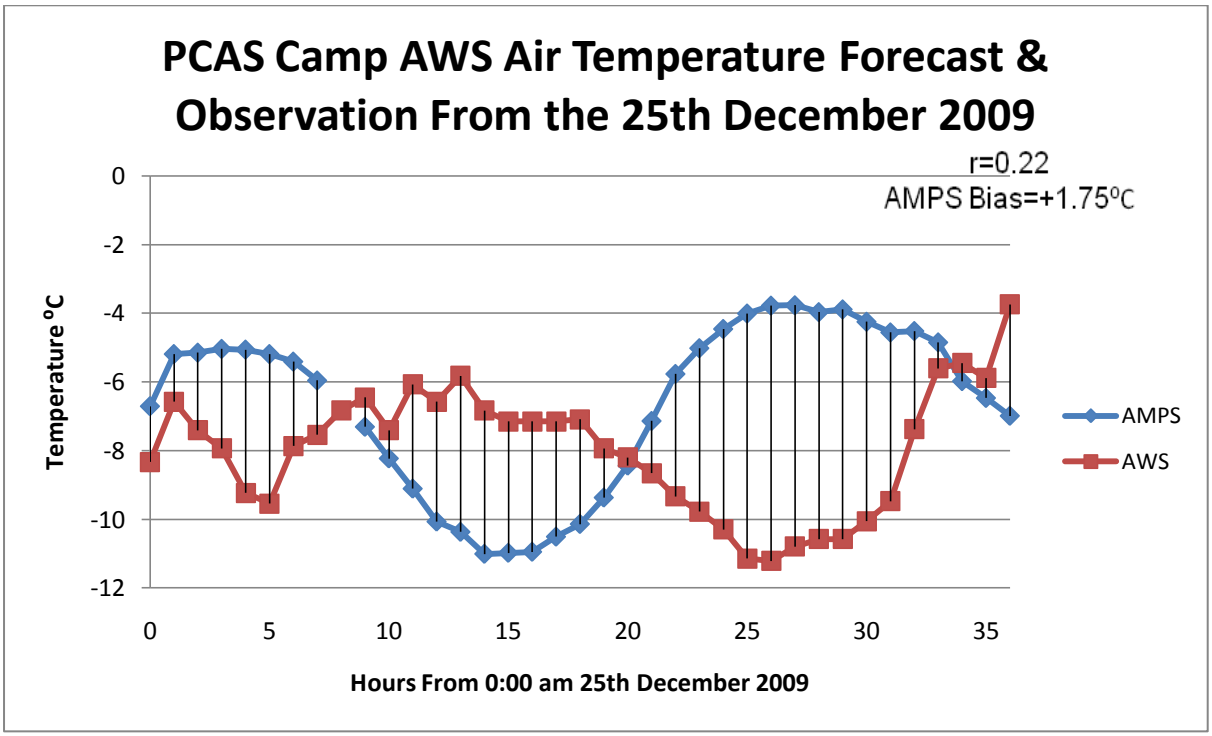


5Div) Wind Direction

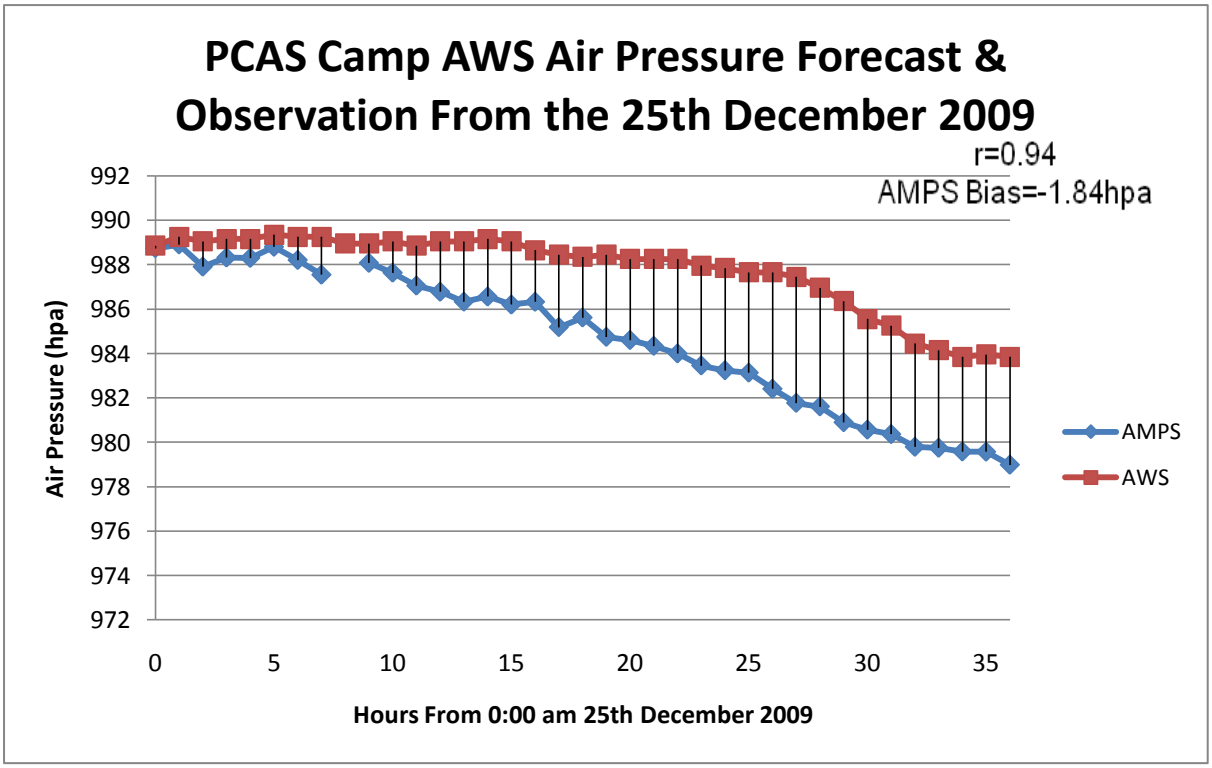


5Dv) Relative Humidity

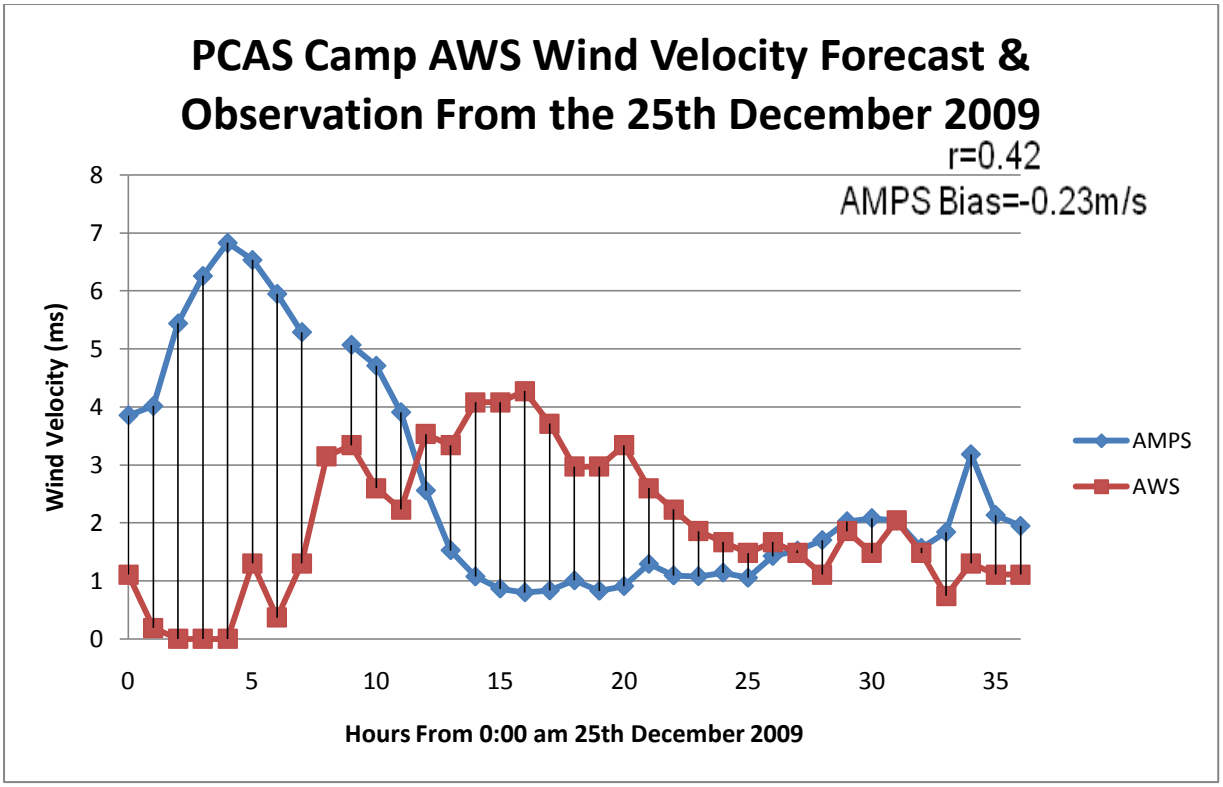
5E) HOBO (PCAS Camp) AWS observations correlated with 0:00am 25th December 2009 AMPS forecast.



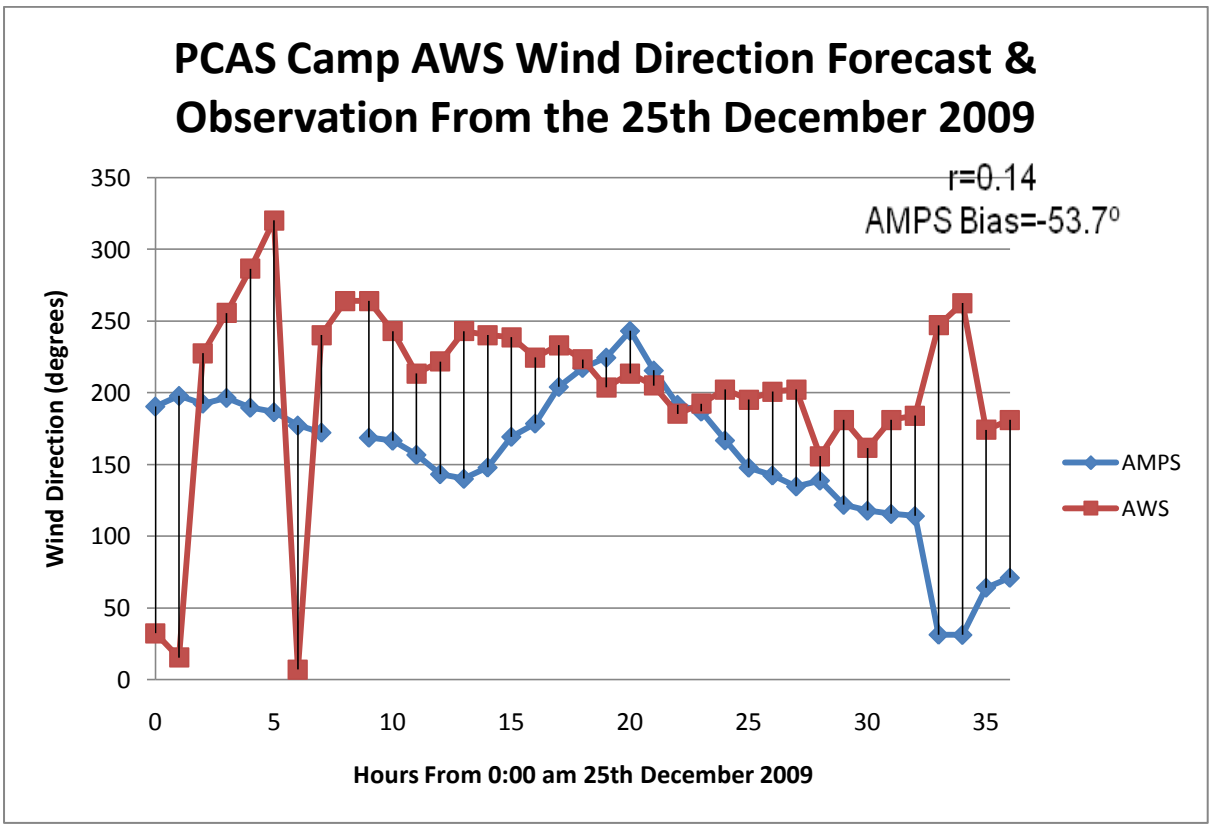
5Ei) Air Temperature



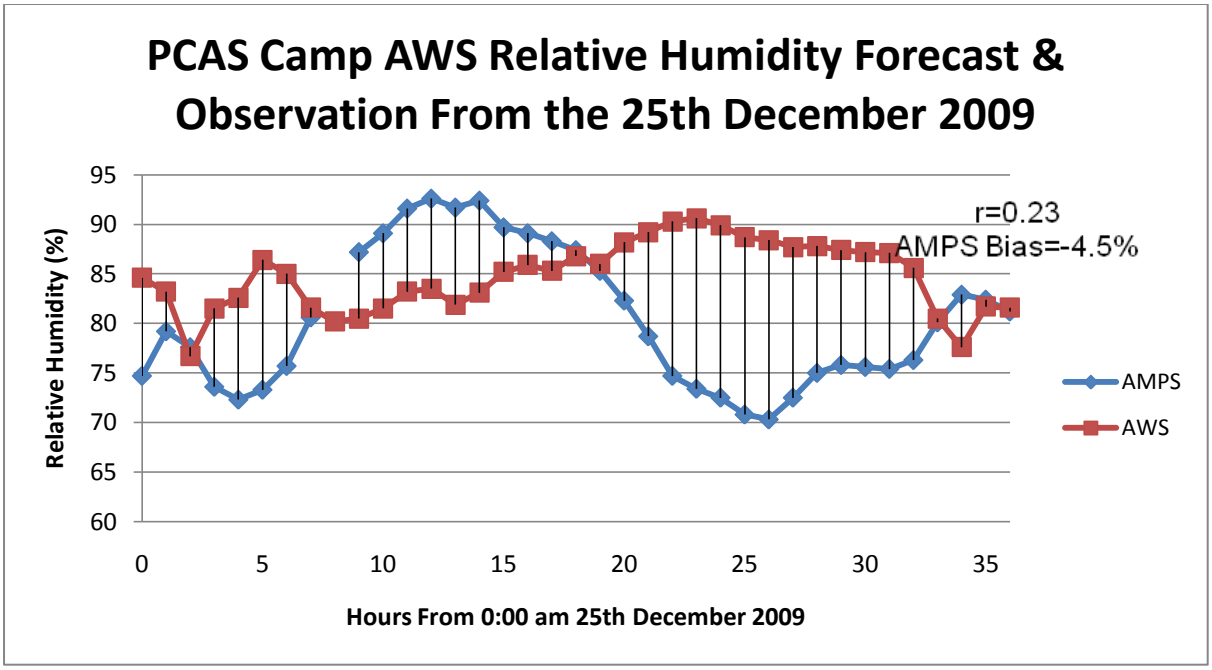
5Eii) Air Pressure



5Eiii) Wind Velocity



5Eiv) Wind Direction



5Ev) Relative Humidity

Appendix 6

				Wind Direction =		90-(ATAN(G6/F6)*180/PI()+IF(AND(F6<0,G6>=0),180,0)-IF(AND(F6<0,G6<0),180,0))							
	Velocity=	(F6^2+G6^2)^0.5				IF(I6<0,360+I6,I6)							
				F	G	H	I	J					
Time	**HR**	**TSFC**	**T2M**	**U10M**	**V10M**	**vel**	**deg**	**deg 0-360°**	**PMSL**	**PSFC**	**CFRAC**	**°C**	**hpa**
25/12/2009 0:00	0	269.82	266.44	-3.79	0.7	3.854102	-79.5356	280.4644	99238.05	98873.9	0	-6.71	988.739
25/12/2009 12:00	0	262.97	254.16	-0.54	0.21	0.579396	-68.7495	291.2505	99119.38	98755.35	0	-18.99	987.5535
26/12/2009 0:00	0	270.25	266.3	3.04	-1.34	3.322228	113.7874	113.7874	98727.73	98365.7	0	-6.85	983.657
26/12/2009 12:00	0	262.47	255.42	-0.21	0.6	0.635689	-19.29	340.71	98570.85	98209.46	0	-17.73	982.0946
27/12/2009 0:00	0	271.94	266.85	-0.35	1.77	1.804273	-11.1854	348.8146	98542.87	98181.53	0	-6.3	981.8153
27/12/2009 12:00	0	270.22	263.9	1.39	0.74	1.574706	61.97032	61.97032	98545.15	98184.4	0	-9.25	981.844
28/12/2009 0:00	0	272.77	266.86	-5.73	4.64	7.373093	-51.0004	308.9996	98745.71	98384.95	0	-6.29	983.8495
28/12/2009 12:00	0	269.69	266.32	-0.66	2.79	2.867002	-13.3092	346.6908	98981.32	98619.41	0	-6.83	986.1941
29/12/2009 0:00	0	273.06	269.31	-3.71	3.85	5.346644	-43.9391	316.0609	99260.11	98898.27	0	-3.84	988.9827
29/12/2009 12:00	0	268.07	261.46	-1.01	2.69	2.87336	-20.5794	339.4206	99496.57	99133.16	0	-11.69	991.3316